THE JOURNAL

OF

"The Royal Aeronautical Society"

with which is incorporated "The Institution of Aeronautical Engineers"

Edited for the Council by Captain J. LAURENCE PRITCHARD, Hon. Fellow

No. 212. AUGUST, 1928. Vol. XXXII.

NOTICES

List of Members

A new list of members is being prepared and will go to press in September. It is important that members should notify the Secretary as early as possible of any change of address since the last list was printed, or any alteration in their titles.

Examinations

Provided a sufficient number of entries are received, the examinations for Associate Fellowship will be held at the Society's offices during the week beginning September 17th, and those for Associate Membership during the week beginning September 24th. Candidates should advise the Secretary as soon as possible of their intention to take the examination, so that the necessary arrangements can be made. The latest dates for entry are August 17th and 24th respectively.

Elliott Memorial Prize

The Elliott Memorial Prize for 1928 has been awarded to C. V. Brown for his paper on "The Technical Problems of Long Distance Flying."

Book Wanted

The Secretary would very much appreciate a copy of the last edition of the Aviation Pocket Book, by R. Borlase Mathews, no copy of which is in the Library of the Society.

Elections

A meeting of the Grading Committee was held on Tuesday, July 10th. Their report was presented to the Council and the following decisions were recorded:—

Associate Fellows.—Mr. M. J. Berlyn, Mr. S. R. Mullard, Mr. M. Roushdy, Major Chichester Smith and Mr. H. M. Yardley.

Associate.—Mr. W. C. Bagnall.

Students.—Mr. J. T. Dyment and Mr. R. D. Samuels.

Companion.—Colonel Stedman Hanks.

Royal Air Force

About 120 officers will be required by the Royal Air Force for flying duties during the next few months. Applications are accordingly invited from suitable candidates, who must be between the ages of 18 and 25, well educated and of good eyesight and physique.

Short service commissions are granted for five years' service on the active list and four in the reserve. A small number of commissions may be extended to ten years on the active list and four in the reserve.

Accepted candidates enter as pilot officers on probation with pay of about £273 a year increased on promotion to flying officer normally after 18 months' service to about £343. Officers also receive free quarters, etc., or where these are not available cash allowances in lieu amounting at present to about £141 a year. A gratuity of £375 is issued on termination of five years on the active list or a gratuity of £1,000 on termination of 10 years on the active list should an extension be granted.

Pilot officers undergo training at a Flying Training School for about a year and are then posted to a service squadron for duty.

Application forms and full details of the conditions of service can be obtained from the Secretary, Air Ministry, Kingsway, London, W.C.2.

Portrait of the late Flight-Lieutenant Kinkhead

A committee has been formed with the purpose of having a painting made of the late Flight Lieutenant Kinkhead, with the object of hanging the portrait in the Royal Air Force Club as a memorial. This officer, who, it will be remembered, lost his life in an attempt to gain the speed record for Great Britain, had a very distinguished war record, having been responsible for bringing down 37 enemy aircraft machines. It is well-known that he took part in the race in 1927 for the Schneider Trophy and that although he did not win he made the shortest time on one round of the course.

Subscriptions for the memorial should be sent, before the end of August, to Captain E. G. Thompson, Royal Air Force Club, 128, Piccadilly, W.1, who will be very glad to give any further particulars that may be required. Cheques should be crossed "Kinkhead-Jones A/c."

Library

The following have been received and placed in the Library:—

Technical Report of the Aeronautical Research Committee for 1926-7.

Reports and Memoranda of the Aeronautical Research Committee—

No. 1114. Charts for the Calculation of Airscrew Thrust and Torque Coefficients. J. D. Coales.

No. 1115. The Importance of "Streamlining" in Relation to Performance. B. M. Jones.

No. 1117. Scale Effect on Three Aerofoils at Low Values of LV., R.A.F. 32, Göttingen 433 and Göttingen 410 with 2 per cent. Centre Line Camber. F. B. Bradfield.

No. 1119. Model Experiments with Rear Slots and Flaps on Aerofoils R.A.F. 31 and R.A.F. 26. H. B. Irving, A. S. Batson and A. L. Maidens.

No. 1120. Analysis of Experiments on an Airscrew in Various Positions within the Nose of a Tractor Body. C. N. H. Lock.

No. 1122. Lift and Drag of Three Model Aeroplanes. H. C. H. Townend.

No. 1123. Wind Tunnel Tests with High Tip Speed Airscrews. The Characteristics of Bi-Convex No. 2 Aerofoil Section at High Speeds. G. P. Douglas and W. G. A. Perring.

No. 1124. Wind Tunnel Tests with High Tip Speed Airscrews. The Characteristics of a Conventional Airscrew Section, Aerofoil R. and M. 322, No. 3, at High Tip Speeds. G. P. Douglas and W. A. Perring.

No. 1125. An Analysis of Some Causes of Discrepancy Between the Calculated Failing Load of the Structure of an Aircraft and the Load at which Failure Occurs on Strength Test. H. B. Howard and K. T. Spencer,

No. 1126. The Distribution of Stress and Strain in the Wöhler Rotating Cantilever Fatigue Test. W. Mason and N. P. Inglis.

No. 1128. Motoring Losses in Internal Combustion Engines. H. Moss.

No. 1129. Heat Transfer in Internal Combustion Engines. H. Moss.

No. 1130. A High Speed Wind Channel for Tests on Aerofoils. T. E. Stanton.

No. 1131. Lift and Torque of an Autogyro on the Ground. H. Glauert.

No. 1132. On the Vertical Ascent of a Helicopter. H. Glauert.

No. 1133. Full Scale and Model Measurements of the Lift and Drag of the Bristol Fighter with M.2 Section Wings. E. T. Jones and A. S. Hartshorn.

No. 1134. Wind Tunnel Tests with High Tip Speed Airscrews. The Characteristics of Airscrew Section R. and M. 322, No. 4, and R.A.F. 32. W. G. A. Perring.

No. 1135. The Effect of Compressibility on the Lift of an Aerofoil. H. Glauert.

No. 1136. The Theory of Pressure Capsules. Part I.—General Discussion. Part II.—The Complete Flat Disc Without Control Spring. A. A. Griffith.

No. 1140. Notes on Performance Testing. H. L. Stevens and A. E. W. Nutt.

No. 1142. Report of the Symbols Sub-Committee.

No. 1145. Wind Tunnel Tests on a R.A.F. 15 Aerofoil with Pilot Planes. F. B. Bradfield and K. W. Clark.

No. 1146. Full Scale and Model Measurements of Lift and Drag of a Bristol Fighter fitted with R.A.F. 34 Wings. J. K. Hardy and A. S. Hartshorn.

No. 1147. Wind Tunnel Tests of Aerofoil R.A.F. 36. F. B. Bradfield and K. W. Clark.

No. 1152. Stresses in a Plate Bounded by a Hyperbolic Cylinder. A. A. Griffith.

Reports of the National Advisory Committee for Aeronautics, Washington—

No. 271. Pressure Distribution Tests on PW-9 Wing Models Showing Effects of Biplane Interference. A. J. Fairbanks.

No. 272. The Relative Performance Obtained with Several Methods of Control of an Over-compressed Engine Using Gasoline. A. W. Gardiner and W. E. Whedon.

No. 279. Tests on Models of Three British Airplanes in the Variable Density Wind Tunnel. G. J. Higgins, W. S. Diehl and G. L. De Foe.

No. 280. The Gaseous Explosive Reaction—The Effect of Inert Gases. F. W. Stevens.

No. 281. The Effects of Fuel and Cylinder Gas Densities on the Characteristics of Fuel Sprays for Oil Engines. W. F. Joachim and E. G. Beardsley.

No. 282. The Performance of Several Combustion Chambers Designed for Aircraft Oil Engines. W. F. Joachim and C. Kemper.

No. 283. A Preliminary Investigation of Supercharging an Air-Cooled Engine in Flight.

No. 284. The Comparative Performance of Roots' Type Aircraft Engine Superchargers as Affected by Change in Impeller Speed and Displacement. M. Ware and E. E. Wilson.

No. 286. Aerodynamic Characteristics of Airfoils—V. N.A.C.A.

Technical Notes of the National Advisory Committee for Aeronautics, Washington—

No. 273. The Effect on Performance of a Cutaway Centre Section. T. Carroll.

No. 274. The Effect of the Sperry Messenger Fuselage on the Air Flow at the Propeller Plane. F. E. Weick.

No. 275. Determination of Propeller Deflection by Means of Static Load Tests on Models. F. E. Weick.

No. 277. Pressure Distribution on Wing Ribs of the VE-7 and TS Airplanes in Flight. Part II.: Pull-Ups. R. V. Rhode.

No. 278. An Automatic Speed Control for Wind Tunnels. A. F. Zahm.

No. 279. Resistance of Streamline Wires. G. L. De Foe.

No. 280. Drag of Exposed Fittings and Surface Irregularities on Airplane Fuselages.

No. 282. Corrosion Embrittlement of Duralumin I. Practical Aspects of the Problem. H. S. Rawdon.

No. 283. Corrosion Embrittlement of Duralumin II. Accelerated Corrosion Tests and the Behaviour of High-Strength Aluminium Alloys of Different Compositions. H. S. Rawdon.

No. 284. Corrosion Embrittlement of Duralumin III. Effect of Previous Treatment. H. S. Rawdon.

No. 285. Corrosion Embrittlement of Duralumin IV. The Use of Protective Coatings. H. S. Rawdon.

No. 286. Preliminary Investigation on Boundary Layer Control by Means of Suction and Pressure with the U.S.A. 27 Aerofoil. E. G. Reid and M. J. Bamber.

No. 287. A Dangerous Seaplane Landing Condition. T. Carroll.

No. 288. The Reaction on a Float Bottom when Making Contact with Water at High Speeds. H. C. Richardson.

National Physical Laboratory Report for the year 1927.

Air Ministry Publications—

No. M.O. 300. International Meteorological Organisation. Commission for the Exploration of the Upper Air. Report of the Meeting in Leipzig, Aug. 29—Sept. 3, 1927.

No. 359 (3rd Edition, Jan., 1925). B.R.2 Aero Engine.

No. 882 (3rd Edition). Lion Series II.B Aero Engine.

Nos. 1120 and 1121. Translated Abstracts of Technische Berichte. Vol. I., 1917/18, and II.

No. 1267. Lion Aero Engines (Series V. and V.a). (Two copies.)

No. 1299. Gamecock Aeroplane. Jupiter VI. Engine.

Memoirs of the Royal Meteorological Society, Vol. II.—

No. 13. On Errors in the Multiple Correlation Coefficient Due to Random Sampling. J. Wishart.

No. 14. Correlations of the World Weather and a Formula for Forecasting the Height of the Parana River. E. W. Bliss.

No. 15. Harmonic Analysis and the Interpretation of the Results of Periodogram Investigations. D. Brunt.

No. 16. Some Studies in Terrestrial Radiation. G. C. Simpson.

No. 17. (A) Discussion, Sir G. T. Walker. (B) Tabulation, E. W. Bliss.

No. 18. An Analysis of the Changes of Temperature with Height in the Stratosphere over the British Isles. L. H. G. Dines.

No. 19. The Lunar Atmosphere Tide at Helwan, Madras and Mexico. S. Chapman and M. Hardman.

M.O., No. 37. Studies of Wind and Cloud at Malta. 286g. G.M. J. Wadsworth.

No. 38. Electric Potential Gradient Measurements at Eskdalemuir, 1913-23. R. A. Watson.
No. 39. 2861 G.M. Results of Observations on the Direction and Velocity of the Upper Air Current over the South Indian Ocean. A. Walter.
No. 40. 286j G.M. The 27-Day Recurrence Interval in Magnetic Disturbance. J. M. Stagg.
No. 47. Regression of Equation with Many Variates. C. E. P. Brooks.
No. 48. The Falling Time of Marine Barometers. E. Gold.

British Engineering Standards Association List of B.S. Specifications for Aircraft Materials and Components—

2L.30, May, 1928. 98 per cent. Aluminium Notched Bars and Ingots for Re-melting Purposes.
2S.3, May, 1928. Hot Rolled Mild Steel Sheets.
2S.4, May, 1928. 5 per cent. Nickel Steel Sheets.
S.P.6, April, 1928. Turnbuckles.
3V.10, May, 1928. Liquid and Jelly Glues.
2V. 11., May, 1928. Gelatine Glue.

U.S.S.R. Scientific Technical Dept. of the Supreme Council of National Economy. Transactions of the Central Aero-Hydrodynamical Institute—

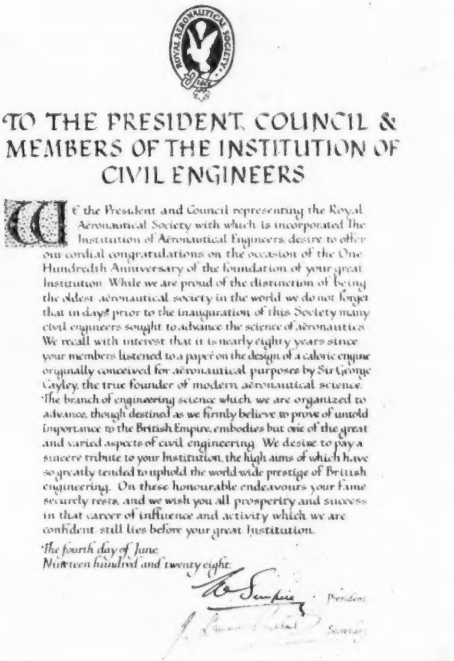
No. 1. Flow of Water in an Open Channel and Flow of Gases in Pipes. N. E. Joukovsky and N. G. Tchentzoff.
No. 2. Problems of Utilising of Energy of Wind. N. Krassovsky and G. Sabinin.
No. 3. Plane Pendulum with Two Degrees of Freedom. V. P. Vetschinkin and N. G. Tchentsoff.
No. 4. (In Russian.)
No. 5. (In Russian.)
No. 6. The Theory of Lattices Applied to a Propelling Screw. A. L. Alexandrow.
No. 7. (In Russian.)
No. 8. Calculation of Torsional Stresses in Propeller Blades. L. C. Leibenzon.
No. 9. (In Russian.)
No. 10. (In Russian.)
No. 11. (In Russian.)
No. 12. Lifting Forces Developing on the Blades of Hydraulic Machines Working in Converging Streams. P. A. Walther.
No. 13. An Investigation of Tuchsherer's Ring Key. H. Carlsen.
No. 14. (In Russian.)
No. 15. The Investigation of Colchugaluminium. I. I. Sidorin.
No. 16. (In Russian.)
No. 17. The Commercial Monoplane C.A.—H.I., Type A.K.I. V. L. Alexandroff.
No. 18. Lifting Forces Developing on Blades of Hydraulic Machines. II., Rotating Blades. P. A. Walther.
No. 19. On the Action of the Two-Dimensional Airstream on a Cylindrical Aerofoil Moving in it. S. A. Chapligin.
No. 23. On the Flexure of Beams having a Double Curvature. P. A. Walther.
No. 25. Standard Specifications for Statik Tests of Airplanes. A. A. Gorjainoff and G. I. Kouzmin.
No. 26. (In Russian.)
No. 27. (In Russian.)
No. 29. A Theory of the Wing of an Aeroplane in a Two-Dimensional Flow. W. W. Goloubew.

No. 32. The Theory of an Ideal Windmill. G. Sabinin.
No. 34. Chemical-Technical Investigation of the Blodd Albumin. A. W. Rakowsky.
No. 35. Wind Pressure on Roofs and Walls of Buildings. K. Bounkin and A. Tcheremoukhin.

Our Times: America Finding Herself. Mark Sullivan.
Popular Guide to Radio. B. Francis Dashiell.
An Investigation of the Thermal Efficiency of a Two-Cycle Petrol Engine. W. Watson and R. W. Fenning.
Aerial A.B.C., April, 1928. (Quarterly.) Aerial A.B.C. Co.
Notes on Giant Aeroplanes. José Weiss and A. Keith.
Construction et Fonctionnement des Moteurs à Combustion Interne. R. E. Mathot.
Indiarubber and Gutta Percha. T. Seeligmann and G. L. Torrilhon.
The Aslib Dictionary. G. F. Barwick.
Proceedings of the Second International Congress for Applied Mechanics, Zurich.
L'Exploration par Fusées de la Tres Haute Atmosphere et la Possibilité des Voyages Inter-Planétaires. R. Esnault-Peltérie.
Aeroplane Timbers. G. R. Keen.
German Dictionary. Bellows.
Flying: The Why and Wherefore. Aero-Amateur.
The Aircraft Handbook. F. H. Colvin and H. F. Colvin.
Flying. W. Lockwood Marsh.
Les Machines volantes de L. de Vinci et le vol a Voile.
Abhandlungen aus dem Aerodynamischen Institut an der Technischen Hochschule Aachen. Vol. I.
Uber laminare und turbulente Reibung. Th. v. Karman.
Zur naherungsweisen Integration der Differentialgleichung der laminaren Grenzschict. K. Pohlhausen.
Der Warmeubergang an einen turbulenten Flussigkeitsoder Gasstrom. H. Latzko.
Grundwasserstromung in einem abfallenden Gelande mit Abfaggraben. L. Hopf and E. Trefftz.
Vol. II. Ein Beitrag sum Spaltflugelproblem. W. Klemperer.
Der Einfluss des Windes auf die Transportleistung. W. Klemperer.
Theoretische Bemerkungen zur Frage des Schraubenfliegers. Th. v. Karman.
Der Schraubenfesselflieger Petroczy-Karman-Surovec. Anhang.
Manual of Wireless Telegraphy (Radio) for the Use of Naval Electricians. S. S. Robison.
Birdflight as the Basis of Aviation. (With Facsimile Title Page of original German Edition.) C. Lilienthal.
Progrès de la Métallurge et leur Influence sur l'Aéronautique. M. Gaetan Py.
Traité Pratique de Navigation Aérienne. A. B. Duval et L. Hebrard.
Les Bordés Travaillants en Construction Navale et Aéronautique. L. L. Kahn.
Considerazioni sulle Controeliche. C. Ferrari.
Deduzione della polare dell'apparecchio dalla polare delal velatura principale. M. Pannetti.
Annuario 1928 (anno VI.). Ministero del l'Aeronautica, Rome.
The Industrial Arts Index, 1926-27. H. W. Wilson.
Cyclones. M. Rondeleux.
Bulletin of the Tokio Institute of Physical and Chemical Research, Vol. III.
Der Motor der Bremen. Junkers.
A Navegacao do "Argos." J. de Castilho.
Report in Four Volumes of the International Air Congress, Rome, 1927.
The Italian Navy in the World War, 1915-1918. (Hist. Sec., Roy. Itn. Navy.)

Dyke's Aircraft Engine Instructor. A. L. Dyke.
Index Generalis. Edn. Spes., Paris.
V.D.I. Special Number, June, 1928. Berlin.
The War in the Air, Vol. II. H. A. Jones.
Airmen or Noahs. M. F. Sueter.
Air Ministry Directorate of Civil Aviation Report on the Progress of Civil Aviation.
Pilot's "A" Licence. 2nd Edition. J. F. Leeming.
A.B.C. of Flight. W. L. Le Page.

J. LAURENCE PRITCHARD, *Secretary.*



TO THE PRESIDENT COUNCIL & MEMBERS OF THE INSTITUTION OF CIVIL ENGINEERS

The President and Council representing the Royal Aeronautical Society with which is incorporated The Institution of Aeronautical Engineers desire to offer our cordial congratulations on the occasion of the One Hundredth Anniversary of the foundation of your great Institution. While we are proud of the distinction of being the oldest aeronautical society in the world we do not forget that in days prior to the inauguration of this Society many civil engineers sought to advance the science of aeronautics. We recall with interest that it is nearly eighty years since your members listened to a paper on the design of a caloric engine originally conceived for aeronautical purposes by Sir George Cayley, the true founder of modern aeronautical science. The branch of engineering science which we are organized to advance, though destined as we firmly believe to prove of untold importance to the British Empire, embodies but one of the great and varied aspects of civil engineering. We desire to pay a sincere tribute to your Institution, the high aims of which have so greatly tended to uphold the world wide prestige of British engineering. On these honourable endeavours your fame securely rests, and we wish you all prosperity and success in that career of influence and activity which we are confident still lies before your great Institution.

The fourth day of June
Nineteen hundred and twenty eight

President

Secretary

Photograph of address by the Society to the Institution of Civil Engineers on the occasion of the Hundredth Anniversary of the latter's foundation.

WILBUR WRIGHT MEMORIAL LECTURE DINNER

On the occasion of the delivery of the Wilbur Wright Memorial Lecture by Mr. Handley Page, C.B.E., F.R.Ae.S., before the Royal Aeronautical Society, the Annual Council Dinner of the Society was held at the Athenæum Club.

Following the dinner, in view of the recent loan of the original Wright machine to the Science Museum, it was thought fitting to send to Mr. Orville Wright an illuminated address, a photograph of which appears on the next page. Those who signed the address before it was finally sent to Mr. Orville Wright were:—Air Vice-Marshal Sir John Higgins, K.B.E., C.B., D.S.O., A.F.C., Air Member for Supply and Research; Sir Richard Glazebrook, K.C.B., F.R.S., F.R.Ae.S., Chairman, Aeronautical Research Committee; Sir Joseph Petavel, K.B.E., D.Sc., F.R.S., M.I.Mech.E., F.R.Ae.S., Director, National Physical Laboratory; Sir Henry Lyons, D.S.O., F.R.S., Director, Science Museum; Dr. F. W. Lanchester, Hon. LL.D., F.R.S., Hon. F.R.Ae.S., M.Inst.C.E., M.I.Mech.E., M.I.A.E.; Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S., Zaharoff Professor of Aeronautics; Mr. H. T. Tizard, C.B., A.F.C., F.R.S., F.R.Ae.S., Member of Council; Mr. A. E. L. Chorlton, C.B.E., M.Inst.C.E., Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., Director of Technical Development; Sir Edward Crowe, C.M.G., Comptroller-General of the Department of Overseas Trade; and the following members of the Royal Aeronautical Society with which is incorporated the Institution of Aeronautical Engineers:—Colonel the Master of Sempill, A.F.C., A.F.R.Ae.S., President; Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O., Vice-President; Mr. Griffith Brewer, F.R.Ae.S., Member of Council; Major J. S. Buchanan, O.B.E., A.M.I.Mech.E., F.R.Ae.S., Member of Council; Mr. A. E. L. Chorlton, C.B.E., M.Inst.C.E., M.I.Mech.E., A.F.R.Ae.S., Member of Council; Captain F. T. Hill, F.R.Ae.S., M.I.Ae.E., B.Sc., Wh.Ex., Member of Council; Captain A. G. Lamplugh, A.F.R.Ae.S., M.I.Ae.E., Member of Council; Major A. R. Low, F.R.Ae.S., Member of Council; Mr. W. O. Manning, F.R.Ae.S., Member of Council; Major R. H. Mayo, O.B.E., F.R.Ae.S., Member of Council; Lieut.-Colonel M. O'Gorman, C.B., D.Sc., F.R.Ae.S., Member of Council; Mr. F. Handley Page, C.B.E., F.R.Ae.S., Member of Council; Mr. T. O. M. Sopwith, C.B.E., F.R.Ae.S., Member of Council; Mr. H. E. Wimperis, O.B.E., F.R.Ae.S., Member of Council; Major D. H. Kennedy, O.B.E., F.R.Ae.S., Honorary Treasurer; Mr. J. E. Hodgson, Honorary Librarian; Captain J. Laurence Pritchard, Hon. F.R.Ae.S., Secretary and Editor.

To ORVILLE WRIGHT

Founder Member of the Royal Aëronautical Society

WE, the President and Council of the Royal Aëronautical Society with which is incorporated The Institution of Aëronautical Engineers, assembled with our guests at the Athenaeum following the delivery of the 16th Wilbur Wright Memorial Lecture, desire to send you this small tribute of our sincere esteem. We are grateful to you for having so carefully restored the original Wright machine, evolved through the mechanical genius of your Brother and yourself, in which, on December 17th, 1903, you separately made the first flights ever achieved by man in a power-driven aeroplane. Further, we greatly appreciate the renewed evidence of your goodwill in sending this historic machine to England and not less the distinction you have thereby conferred on our renowned Science Museum where it is now exhibited for all the world to see.

The thirtieth of May
Nineteen hundred & twenty eight.

THE PRESIDENT & COUNCIL

Wilbur Wright Lecturer: 1928

J. Lawrence Pritchard Secretary

THE GUESTS

A.M.S.R. Air Council

Director N.P.L.

Secretary D.S.I.R.

Comptroller General D.G.T.

Chairman A.R.C.

Director of the Science Museum

Zaharoff Professor of Aeronautics

Director Technical Developments Air Ministry

Assistant S.M.M.T.

WILBUR WRIGHT MEMORIAL LECTURE

30TH MAY, 1928

The 16th Wilbur Wright Memorial Lecture was delivered before the Royal Aeronautical Society with which is incorporated the Institution of Aeronautical Engineers, on Wednesday, May 30th, 1928, at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, by Mr. F. Handley Page, Fellow. There was an extremely distinguished audience and the lecture was followed by the Annual Council Dinner, particulars of which are given elsewhere in this issue.

The PRESIDENT of the Society, Colonel the Master of Sempill, said: The Wilbur Wright Memorial Lecture is recognised as being not only the most important lecture given before the Royal Aeronautical Society, but the most important lecture given before any aeronautical society, as it is given in memory of the great pioneer Wilbur Wright, who with his brother made the first flights ever made by man in a power-driven aeroplane nearly 25 years ago. It would not be possible for anyone to add lustre to the name of Wilbur Wright, and I am sure that he would strongly deprecate any lengthy tributes of this nature. You will remember that when the Wright machine was first flown in France in 1908, Mr. Wilbur Wright was approached by Mr. F. W. Lanchester, who only succeeded in learning that the bird that talked the most—the parrot—was a bad flier. A little later—at the end of 1908—Mr. Lanchester read a paper before this Society, entitled, "The Wright and Voisin types of Flying Machines." He sent Mr. Wilbur Wright a copy of this paper, who replied in a very brief letter:—"In glancing over the address I note such differences in matters of information, theory, and even ideals, as to make it quite out of the question to reach common ground by mere talk, so I think it will save me much time if I follow my usual plan and let the truth make itself apparent in actual practice."

It will, however, be very appropriate on this occasion to say how much we appreciate the generous action of Mr. Orville Wright in sending to the Science Museum the original machine, which he had specially reconditioned before despatch. Not only has he greatly honoured the aeronautical community by so doing, but the country at large.

Your Council are sending an appropriate message to Orville Wright to mark this great occasion.

The Wilbur Wright lecturer this year is so well known, not only in this country but throughout the aeronautical world, as to require no introduction. Last year you will remember that we had the privilege of listening to Professor Prandtl, of Göttingen, and next year we hope to be able to have the privilege of listening to someone from the United States of America.

On, I think, the first occasion that Mr. Handley Page addressed this Society—early in 1909—the audience consisted of the Secretary and one other gentleman now very well known to you as the aeronautical correspondent of one of our most important papers. Writing of this occasion, Mr. Handley Page was referred to as:—"A young man of the largest size was discussing with immense enthusiasm and unfaltering diction upon the inherent stable aeroplane. He was a man whose appearance of youthful vigour and faith, accompanied by an all-absorbing enthusiasm, almost belied his solid experience and attainments." At that time Mr. Handley Page was something of an *enfant terrible*, and to this day he is one of the most remarkable personalities in a cause which boasts of more young-man successes than any other.

Mr. Handley Page started his career as an electrical engineer, and had achieved some eminence in his profession when in 1906 he first commenced to take an active interest in aeronautics. Had aeronautics not laid a hold on him there can be but little doubt that he would have gone to America, as a tempting offer had been made to him to join the Experimental Department of the Westinghouse Company.

During the early experimental period Mr. Handley Page had the assistance and co-operation of the late Mr. Weiss. In 1908 Mr. Handley Page formed a company—the first of its kind—to design and construct aircraft. In 1909 he erected works at Barking, and passed very many years facing the ups and downs of the early pioneer with courage and equanimity. In 1912 new works were established at Cricklewood, twice the size of those at Barking. During the war period Mr. Handley Page became famous—assisted by the Royal Naval Air Service—as the designer and constructor of the twin-engined bombers bearing his name. Of all the large twin-engined machines the Handley Page was not only the first of its kind, but has proved to be the most successful.

Since the war Mr. Handley Page has become even more famous in connection with the particular device that he is to speak to us about this evening. In view of the development of the aileron by the Wright Brothers, this lecture by Mr. Handley Page is most appropriate.

16TH WILBUR WRIGHT MEMORIAL LECTURE

BY F. HANDLEY PAGE, C.B.E., F.R.AE.S.

In the Wilbur Wright lectures we commemorate, and pay our tribute to, that pioneer work upon which the art of flying is founded and it is only now that carrying our minds back to those early days we see how thorough were the methods which led to success. The work of Lilienthal in gliding with curved wings—brought to an untimely end through lack of control—had shown that the secret of success was to be found in free flight experiment. Then came the great contribution of the Wrights, who discarded Lilienthal's acrobatic control and carrying through the whole modern programme of wind tunnel research, detail design and construction, found out by practical flying that essential feature of control which has been used in practically every aeroplane that has been flown.

In the original Wright aeroplane, as in all its successors of fixed wing area, the only means used for varying the lift was by alteration of the angle of incidence or of the camber of the wing either by warping or by the equivalent use of ailerons. Such a variation in lift was, and is, used either for the purpose of varying the speed of the aeroplane, or applied to one portion of the wing surface only, for controlling the aircraft.

In the development of flying which is taking place by the use of the slotted wing we are extending those original angular limits within which aircraft may be safely flown and the original Wright control used, and further, are so improving the control as to make safe that range of stalled flight in which the original type of control was and is of no avail.

The inherent and fundamental difficulty of the breakdown of air flow over the upper surface of a wing section—known as " burbling "—has, due to the stalling of a normal unslotted wing, placed a lower safe limit on the flying speed of an aircraft, and has likewise set a lower limit, below which, owing to lack of increased lift with increased angle, the aircraft controls cease to respond to the control movements of the pilot.

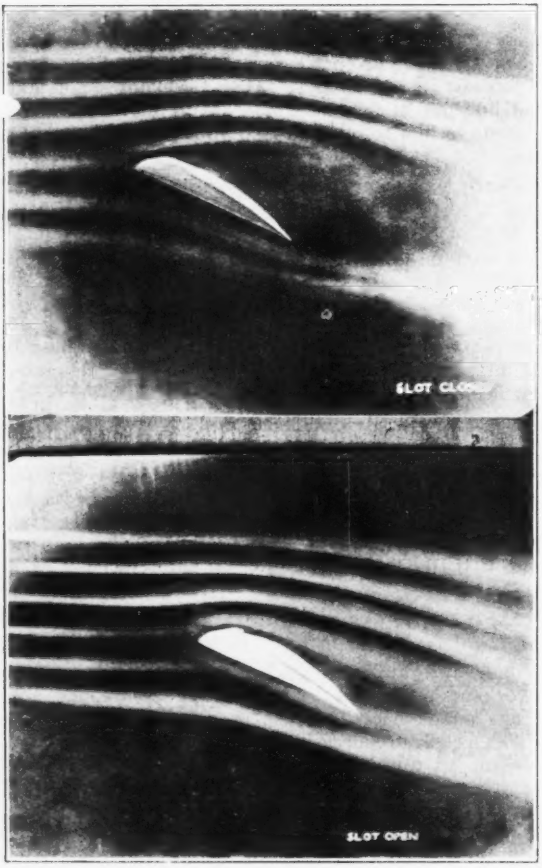


FIG. 1.

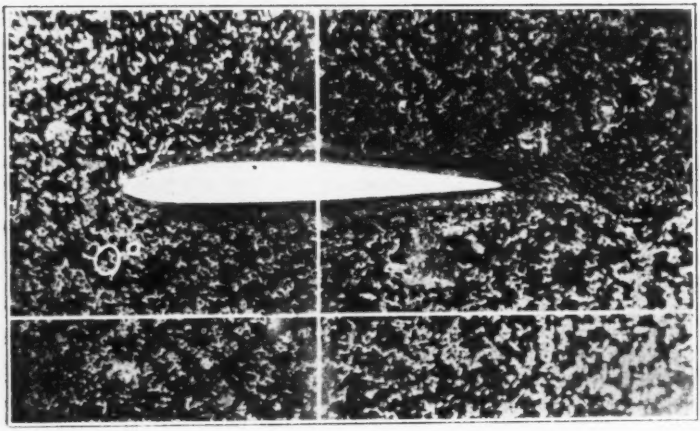


FIG. 2.

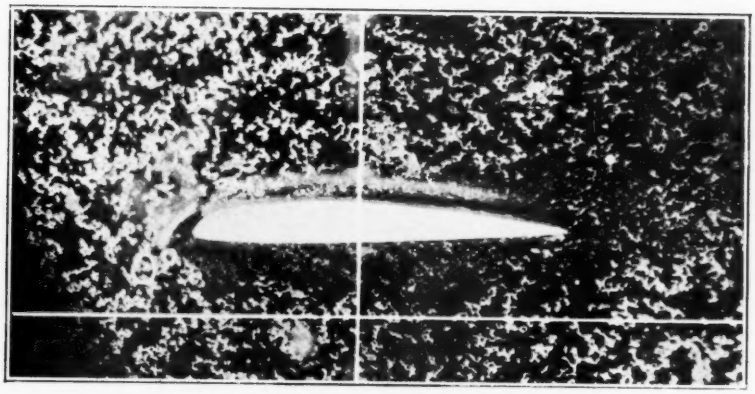


FIG. 3.

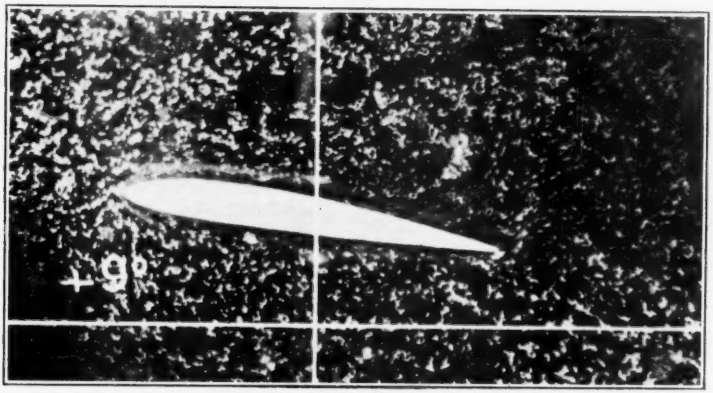


FIG. 4.

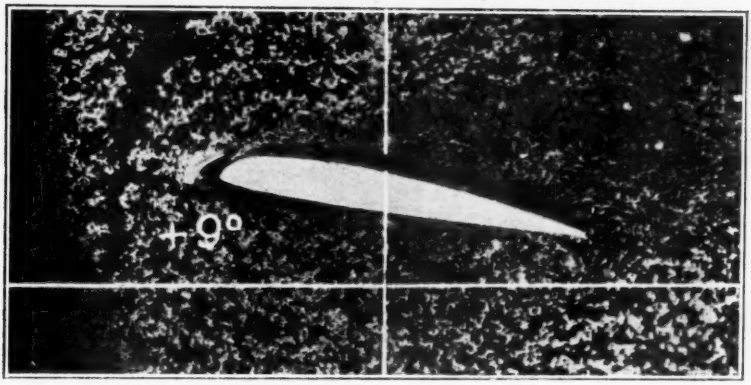


FIG. 5.

The increased range of angles at which lift can be obtained with the slot is limited only in degree by the number of slots used. Its ultimate development must depend on mechanical considerations and it may well be that, with further mechanical experience, which is gained but slowly, larger numbers of slots will be used in a wing, particularly now that the fashion for their use has set in, for fashion and custom, as in all the arts and commerce, settles to a very large extent the choice of the pilot and the decisions of the engineer.

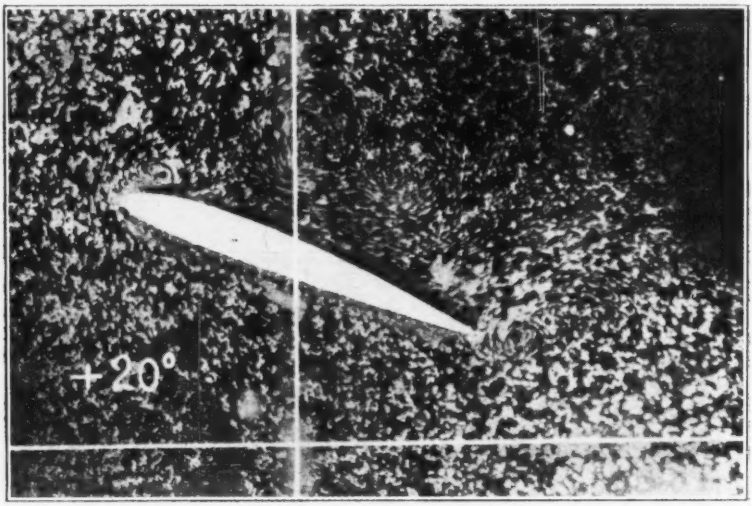


FIG. 6.

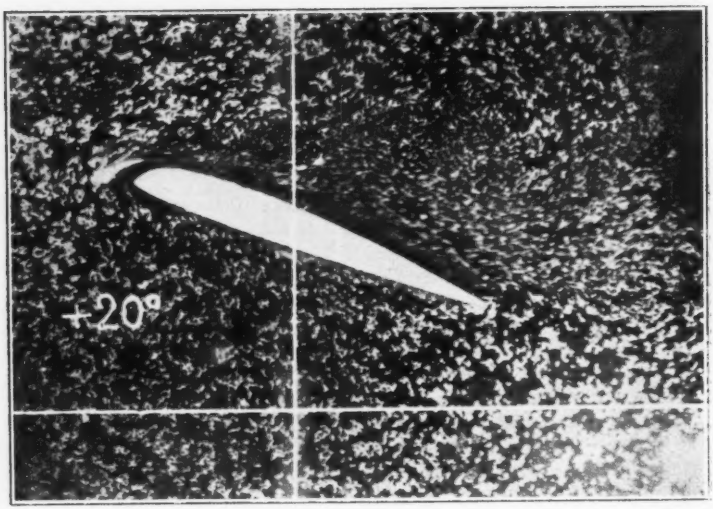


FIG. 7.

Two courses lie open to a designer in the application of the slot. The first and most obvious is to slot the wing throughout its span and, as the range of angles is increased through which useful lift can be exerted upon the aircraft, to obtain a wider speed range and improved performance, provided that the mechanism added does not offset the advantage so gained. The second course

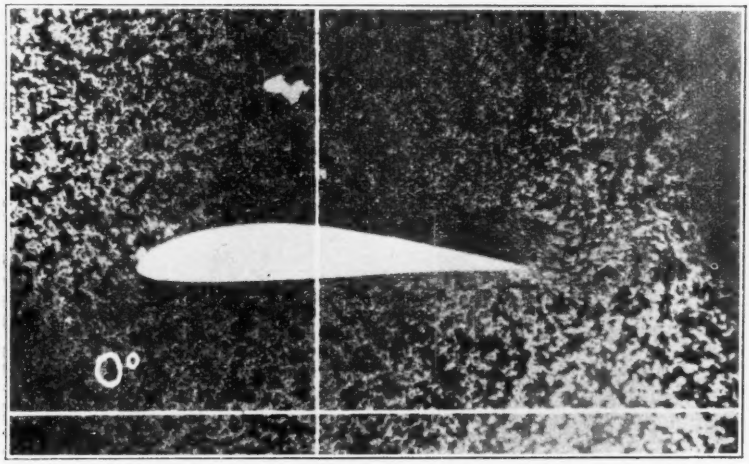


FIG. 8.

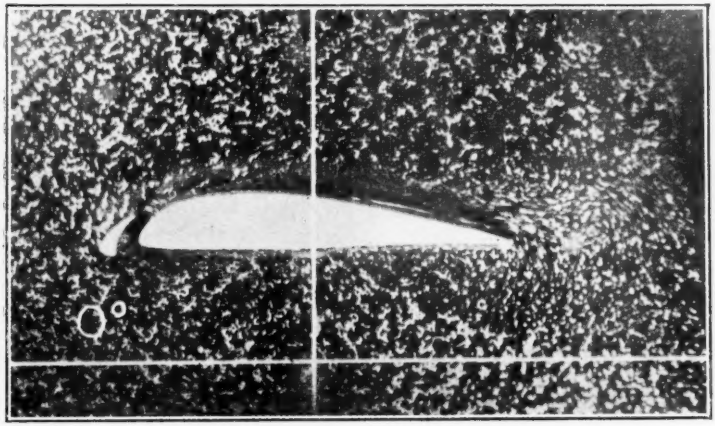


FIG. 9.

is to apply the slot to a portion only of the lifting surfaces and to use the device mainly to give that control at and beyond the stalling speed of the aircraft which is lacking with the ordinary wing.

Let us turn first to the results which have been obtained in the wind channel and see in what way the aerodynamic characteristics of a wing section are altered by the slot. Photographs of air flow in the wind channel show clearly

the difference between the form of flow over the upper surface with the slotted and unslotted plane at large angles of incidence (see Fig. 1).

A further series of photographs (Figs. 2 to 13) show the flow around a plane moved through water on the surface of which light aluminium powder

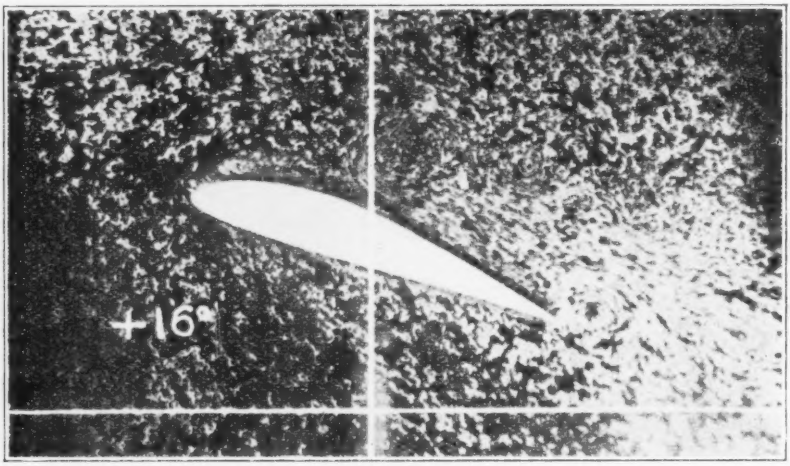


FIG. 10.

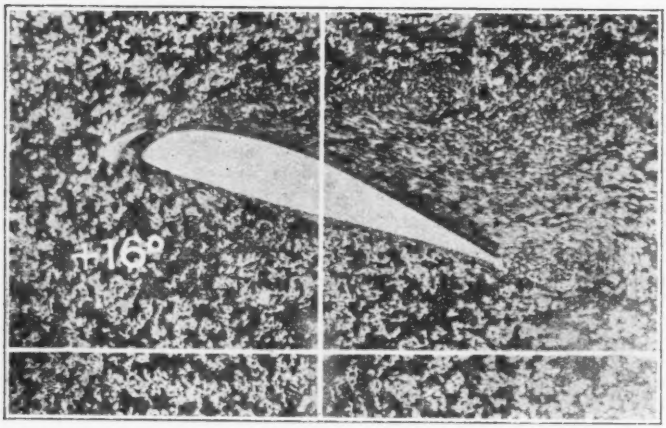


FIG. 11.

has been sprinkled. The first set (Figs. 2-7) are of a R.A.F. 28 section at 0, 9 and 20° angle of incidence respectively with slot open and slot closed. There is little difference between the two conditions until the 20° angle of incidence is reached. Then the suppression of the forward eddy on the back of the plane is clearly marked with slot open.

The second set (Figs. 8-13) were taken with Göttingen 426 at 0, 16 and 26° angle of incidence. The photographs at 16° and 26° angle bring out clearly the two forms of flow with slot open and closed, the eddies over the leading edge which are present when the slot is closed disappearing when the slot is opened.

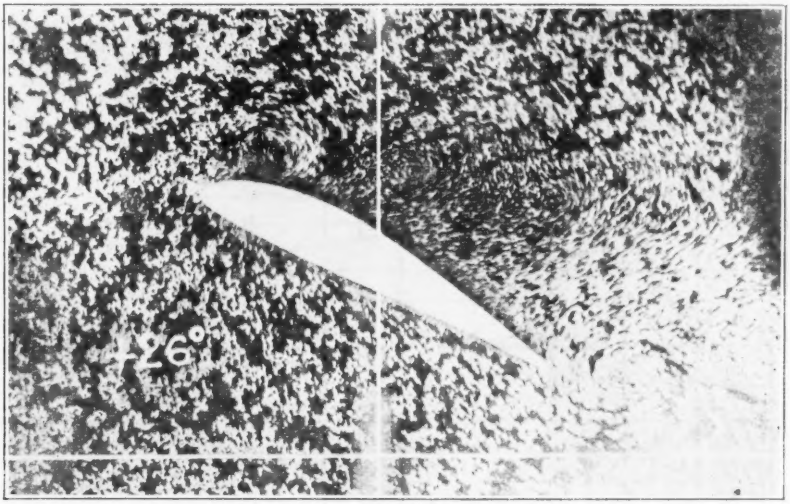


FIG. 12.

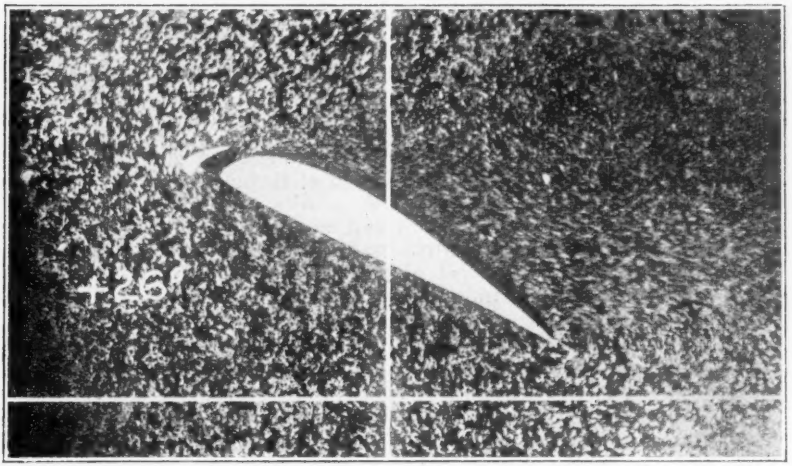


FIG. 13.

These photographs were taken in a small water tank 10ft. long, 6in. wide and 6in. deep. The model is held in a frame and drawn through the water by a light cord attached to the pulley wheel of a small electric motor.

From these qualitative comparisons we turn to detailed wing channel data which is given for representative medium and thick wing sections to add to that available for wings of thinner sections such as R.A.F. 15. It is a matter of interest to-day when structural needs often call for thicker wing sections that increases in lift can be obtained with thick wings comparable in magnitude with those of the thinner sections.

In Fig. 14* are given the results on R.A.F. 31 section, showing with forward slot open an increase in lift of approximately 50 per cent, and the usual decrease in resistance at high angles.

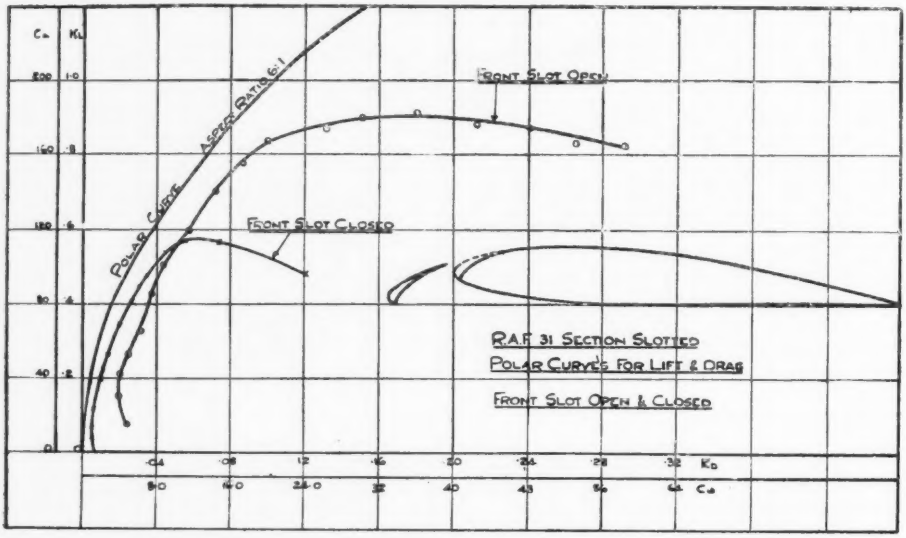


Fig. 14.

On thick wing sections, or on any type of section fitted with a forward slot, it is advantageous to use also the slot in front of the aileron or flap. Fig. 15† shows the latest results obtained on R.A.F. 31 with a rear flap at 20°, the test being taken with the rear slot closed as well as open. It will be observed that the lift of the aerofoil is increased from .92 to 1.03 with the rear flap only, and when the rear slot is used in front of the flap the maximum lift is increased again to approximately 1.18, rather more than 100 per cent. over the original unslotted section.

The use of the slotted rear flap in conjunction with the forward slot is of importance in applying slot design to increase the speed range of an aircraft, as by this means an excessive angle of incidence at landing or taking-off is avoided. For example, with R.A.F. 31 the angle of incidence at which the maximum lift is obtained with the unslotted section is 12.3°, which is increased to 23.8° with the front slot only, but decreased again to 18° when the slotted flap is used, the latter angle well within the range of commercial utilisation.

The position of the hinge point of the rear slotted flap is important and

* See R. & M. No. 1063.
† See R. & M. No. 1119, Fig. 4.

needs to be determined accurately to obtain the best result. Fig. 16* shows the variation in lift on R.A.F. 31, due to variations in the position of the nose point of the rear flap. It will be observed that the maximum lift coefficient varies from .98 to 1.18 according to the position of the flap—a maximum increase of 0.62 over the unslotted section. It would appear that one of the

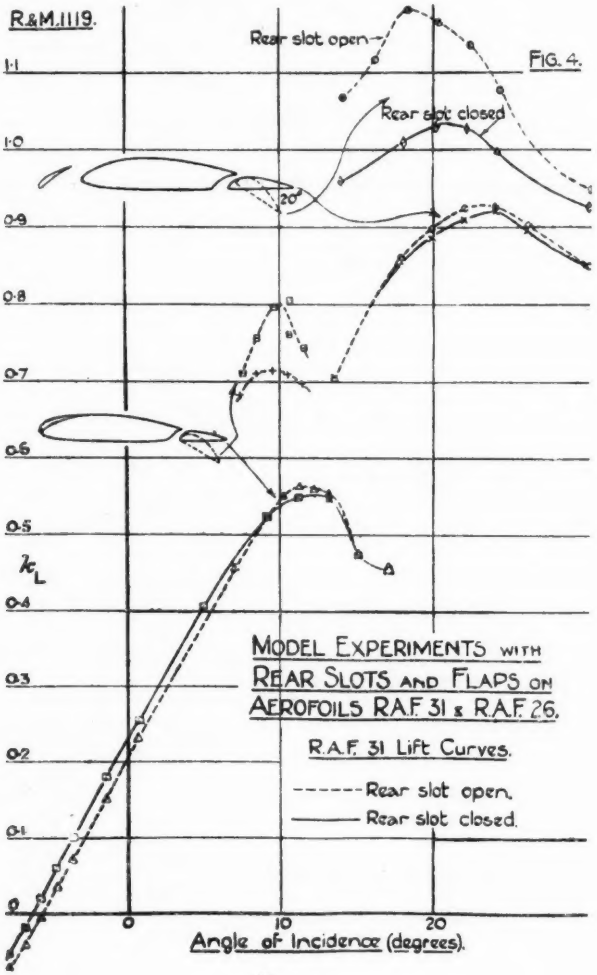


FIG. 15.

determining factors in this matter is the width of the gap at the upper slot opening.

A further interesting result is a test carried out† on Udet high lift thick wing section (see Fig. 17) used in a cantilever wing construction, the lift

* R. & M. 1119, Fig. 3.
† Zeitschrift für Fleytechnik und Motorluftschiffahrt Heft 15 and 16, pp. 174 and 175.

MODEL EXPERIMENTS WITH REAR SLOTS AND FLAPS ON AEROFOILS R.A.F. 31 AND R.A.F. 26.

Contours of lift coefficient, R.A.F. 31.

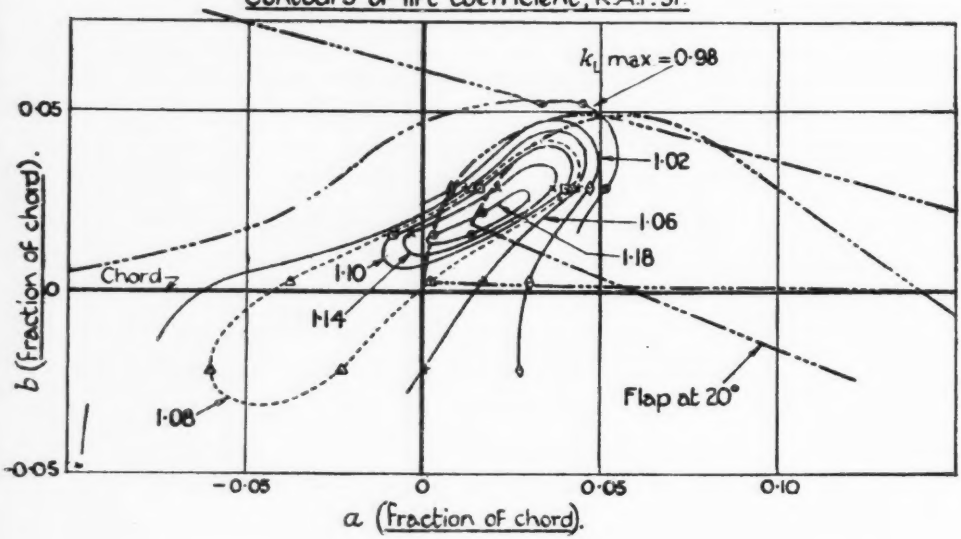
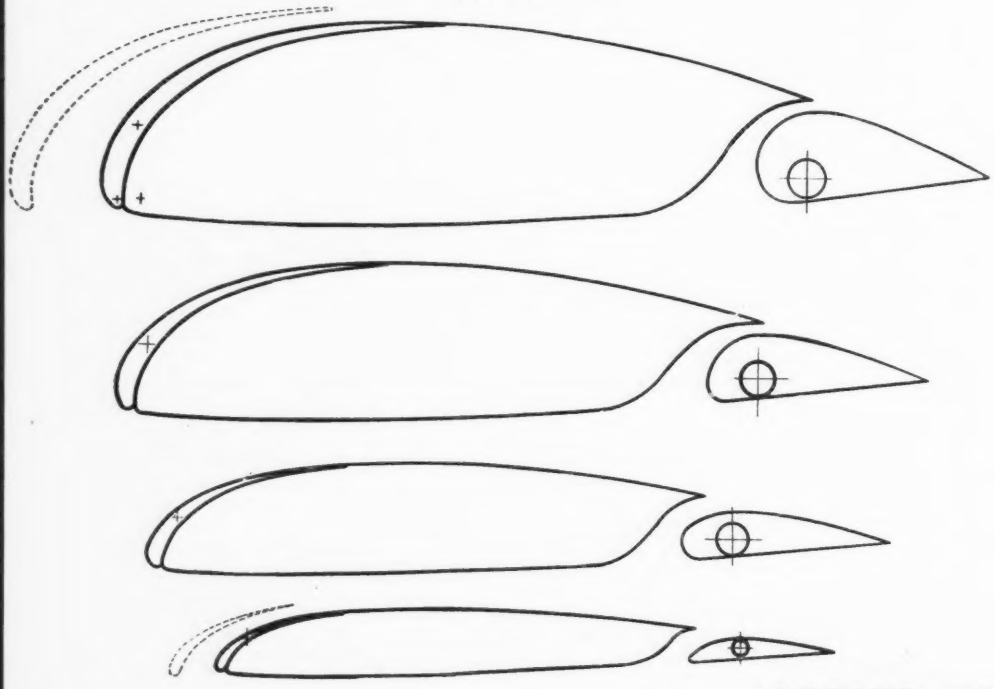


FIG. 16.



UDET TAPERED WING.

FIG. 17.

coefficient with the slot closed and rear flap normal being .85. When this section was fitted with a forward slot and a slotted rear flap at 20°, a lift coefficient of 1.42 was obtained, which with the flap at 30°, was increased to 1.45—an increase of 0.6 over the unslotted section (see Fig. 18).

Full-scale tests have clearly demonstrated that these high lift coefficients with thick wing sections are not diminished, due to scale effect and that there is no falling off in lift as has been experienced with a high lift wing section such as R.A.F. 19. Scale effect seems, however, to vary with different types of slots (Figs. 19 and 20).‡ For example, with a plate type of forward aerofoil of small chord there was little change in maximum lift in full-scale, whereas on the

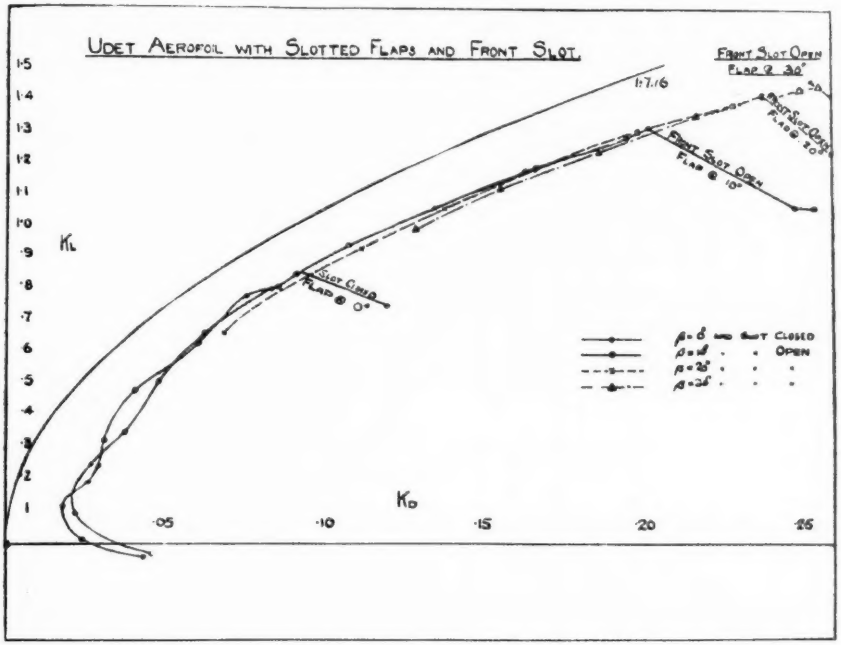


FIG. 18.

cambered large chord forward aerofoil the maximum lift in full-scale was considerably more than that of the model (see Figs. 19 and 20).§

A typical modern section is R.A.F. 28 (see Fig. 21) on which tests have been carried out in our wind channel with a large as well as a small type of forward aerofoil (type " A " with a chord one-sixth that of the main plane; type " B " with a chord one-eighth that of the main plane). The influence of chord width is clearly shown in the results (see Fig. 22). With the larger chord an increase of over 100 per cent. in lift coefficient is obtained with front slot only. The lower portion of the lift curve with a slotted section is shown dotted as with the use of the automatic slot opening at the correct angle the slot is not open for the lower values of the lift curve.

‡ R. & M. 1007.

§ R. & M. 1007, Figs. 9 and 12.

These results are typical of those obtainable with modern slotted wing sections, the lift coefficient with forward slot and slotted flap increasing by as much as 0.6 or in some cases 100 per cent compared with the unslotted section. No longer is the designer limited in choice of wing area by a landing speed

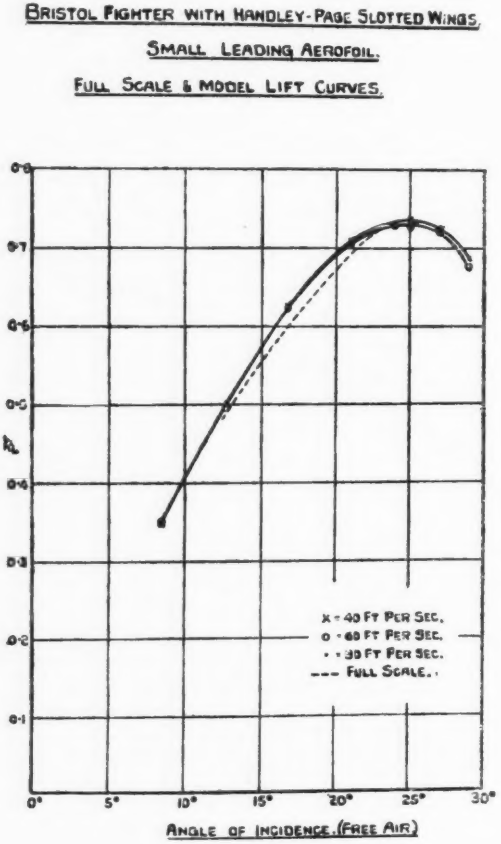


FIG. 19.

associated with a maximum lift coefficient of 0.5 to 0.7, but can choose the section best suited to top speed and climb. The choice of mechanism used will vary with the wing section chosen, but it is probable that for increasing the speed range of an aeroplane the slotted flap will be associated with the forward slot to avoid the otherwise high angle of incidence reached. If a reduction in area is required it is preferable to reduce chord rather than span so as not to increase the induced resistance. The change in profile drag will depend upon the type of slot selected and still further research work is required on the factors affecting profile drag both for front and rear slots.

Control

Let us now turn from the wing completely slotted for its whole span and consider the effect of slotting a portion only of the span. If this portion be that at the leading edge of the wing tips opposite the ailerons these parts of the wing will stall at a much larger and therefore later angle than the centre.

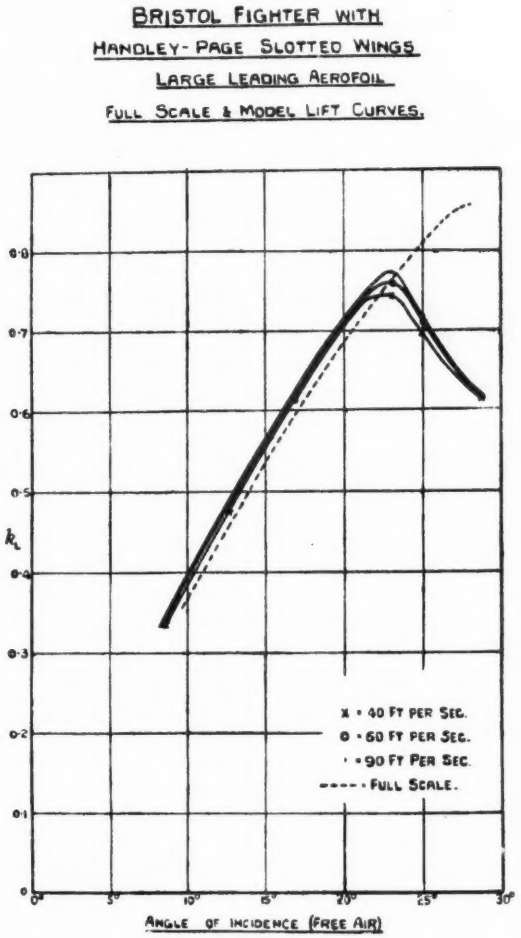


FIG. 20.

As burbling starts at the centre of the wing and proceeds outward, an aircraft so fitted can be flown with the centre section of its wings stalled and the outer tips under normal conditions of air flow. In this state the aeroplane, if rolled, experiences a righting moment similar to that on an ordinary aeroplane flying under normal conditions and, similarly too, the plane responds to aileron movements as in normal flight. Such a machine behaves in fact exactly similar to

R.A.F 28 Section

Fitted with Two Types of Front Slot

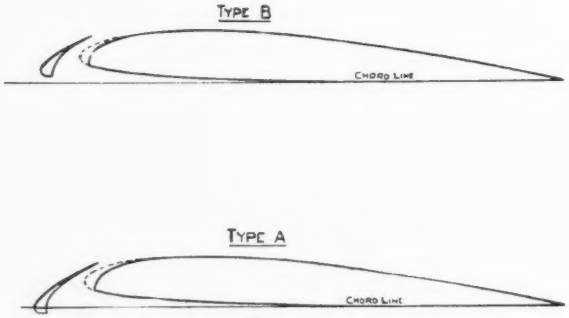


FIG. 21.

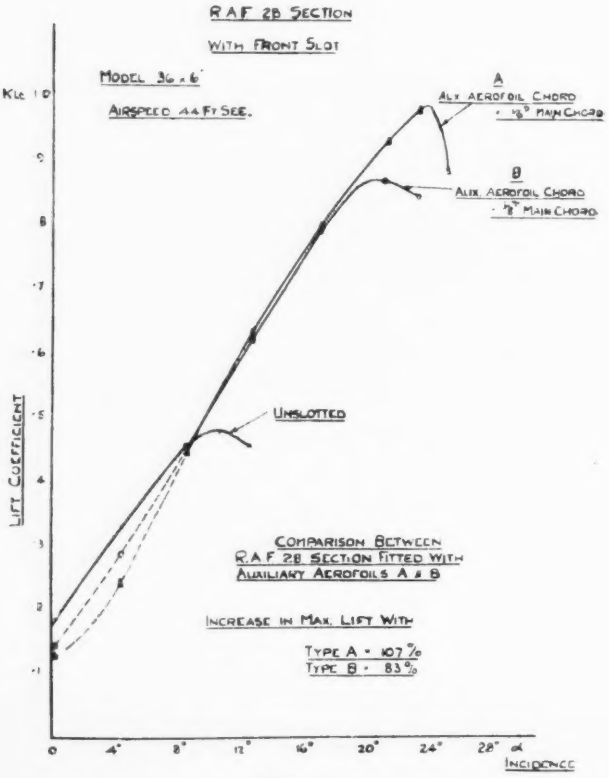


FIG. 22.

one having wings with an excessive " wash-out." As the control surfaces of a normal aircraft are usually inadequate to produce a sufficiently large angle of incidence also to stall the wing tips when so fitted, the use of the slot in this manner extends the range of safe flying and removes the danger arising from the involuntary stall.

Such a slot, if fixed open at all speeds, would cause increased resistance at the smaller angles of incidence—see Fig. 14—and reduced performance. In a similar manner an aircraft with an excessive " wash-out " would have a reduced

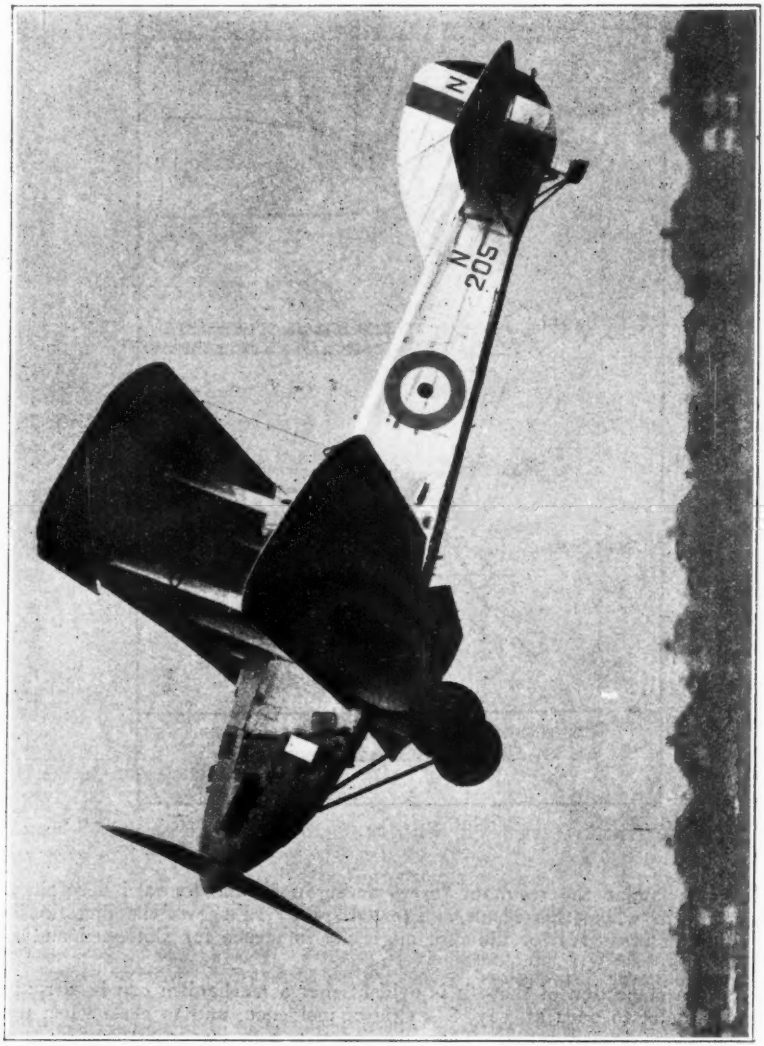


Fig. 23.

performance due to the large negative angles of the wing tips at full speed. To avoid this disadvantage it is essential that the slot should open only as the stalling speed of the aircraft is reached and remain open so long as the aircraft is stalled (see Fig. 23).

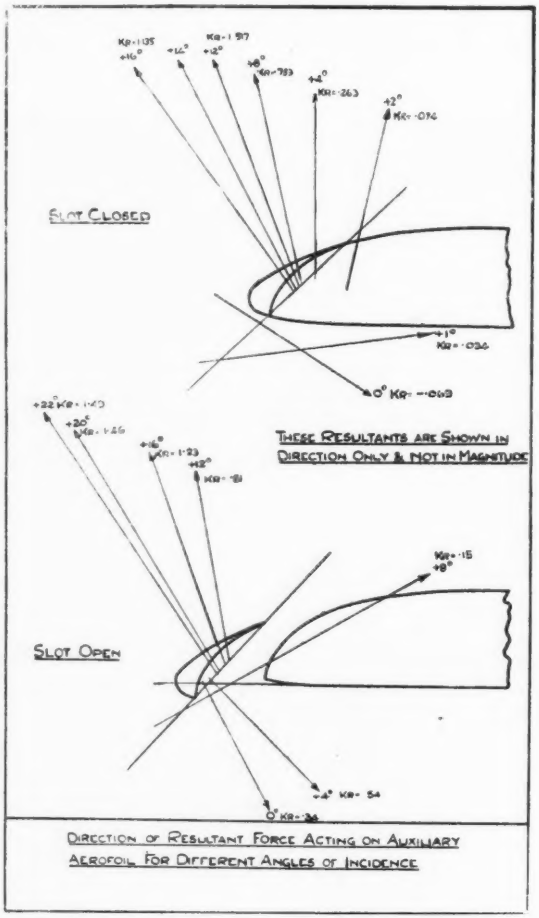

SLOT CLOSED
THESE RESULTANTS ARE SHOWN IN DIRECTION ONLY & NOT IN MAGNITUDE
SLOT OPEN
DIRECTION OF RESULTANT FORCE ACTING ON AUXILIARY AEROFOIL FOR DIFFERENT ANGLES OF INCIDENCE

FIG. 24.

Let us examine the resultant forces acting upon the forward aerofoil and see the way in which this result is effected. Fig. 24 shows the directions of these resultant pressures for different angles of incidence for slot open and slot closed.

From an inspection of these it is evident that a mechanism can be arranged to cause the slot to open at, say, 8° angle of incidence, and to close when open at a somewhat similar angle. There is, however, an important consideration

that must be taken into account, and that is the way in which the forward aerofoil proceeds from its closed position against the main section to the completely open state. In Fig. 25 there are shown two different ways in which the forward aerofoil may be moved, from the same closed to the same open positions, but with greatly different intermediate attitudes of the forward aerofoil.

In the non-parallel link type, shown in the upper half of the illustration, the initial movement of the forward aerofoil is such as virtually to create instead of suppress "burbling," and in consequence to cause a force to act upon the forward aerofoil, tending to close the slot. This intermediate position is shown

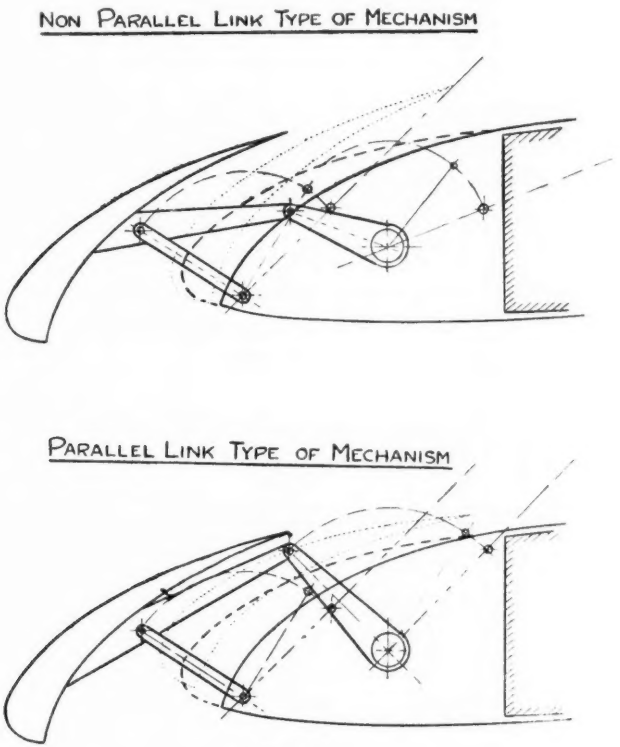


FIG. 25.

"dotted" with an opening at the rear of the slot much greater than that at the lower entry.

If, however, the links be changed in length and in disposition the forward aerofoil can be made to proceed from closed to opened position, so that a slot of correct shape is at all positions formed between the forward aerofoil and the main section. The "dotted" section again shows the intermediate position of the forward aerofoil. The essential difference between the two mechanisms is evident.

Measurements have been made in our wind tunnel of the difference in the values of the torque on the forward mechanism with the two types of slot gear

shown. Fig. 26 shows that with the parallel link type there is an opening torque up to a slot opening 70 per cent. of the full open position when the angle of incidence of the main planes is 10°. On the other hand, with what is termed the non-parallel link type, there is a closing torque in all positions of the forward aerofoil.

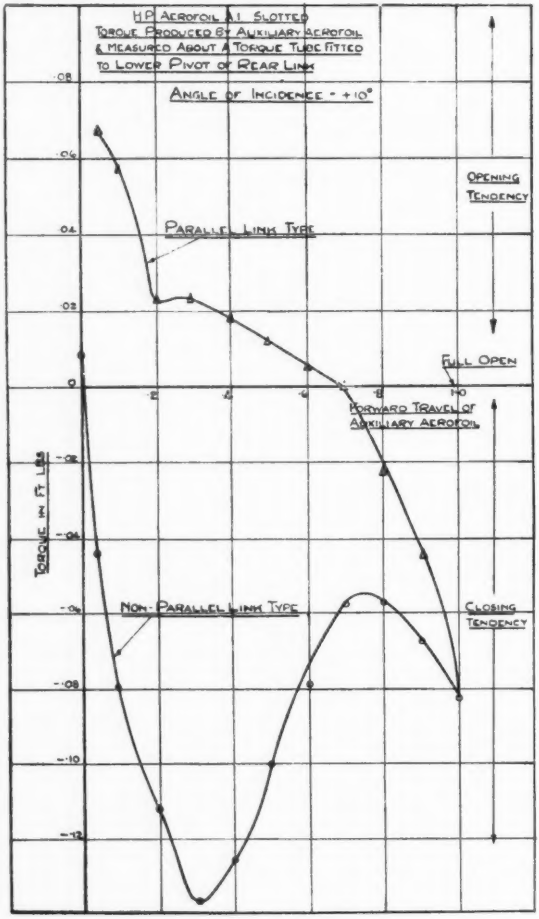


Fig. 26.

Whilst the example has been taken of a two-link mechanism, the means whereby the slot may be made to move automatically are not limited to this type. Fig. 27 shows the way in which the forward aerofoil may be made to move on a sliding bar, guided by rollers; the line of motion being at right angles to the line of action of the resultant forces on the forward aerofoil at the angle at which a change over from closed to open slot is to take place. Similarly, in Fig. 28, the forward aerofoil is shown hinged and swinging forward to open

STRAIGHT LINE ROLLER TYPE
MECHANISM

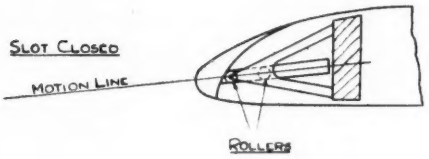
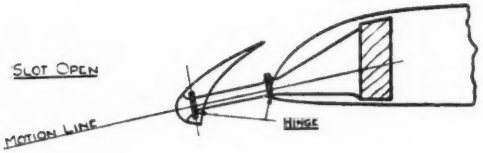
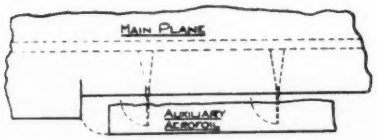


FIG. 27.

HORIZONTAL EXTERNAL LINK
MECHANISM





PLAN VIEW

FIG. 28.

the slot, the hinge line being parallel to the line of action of the resultant forces on the forward aerofoil at the angle of incidence at which the change is to take place.

In the pressure diagrams which have been shown, the pressures were taken over the upper surface only, on the assumption that the forward aerofoil, when the slot was closed, fitted snugly against the main wing section and that there was no pressure exerted between the inner surfaces of the forward aerofoil and the main wing. In actual practice, however, it is impossible to ensure that both leading and trailing edges of the aerofoil shall fit exactly on the main wing. In Fig. 29 the wing section is shown diagrammatically with the forward aerofoil either fitting tight on its front edge, or at the rear edge. In the first case the forward aerofoil has an additional suction exerted upon its inner surface which tends to retard the opening, and in the latter case it receives a positive pressure,

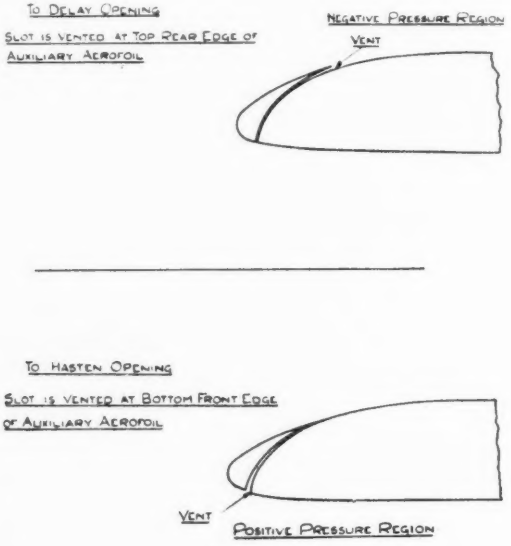

To Delay Opening
Slot is vented at top rear edge of Auxiliary Aerofoil
Negative Pressure Region
Vent
To Hasten Opening
Slot is vented at bottom front edge of Auxiliary Aerofoil
Vent
Positive Pressure Region

FIG. 29.

tending to accelerate the opening. In consequence, with the addition of the pressures or suctions on the inner surface, there is a considerable change in the direction of the resultant pressures on the forward aerofoil. Fig. 30 shows the difference due to taking these added forces into account.

At an angle of incidence of 2° the resultant force acting upon the forward aerofoil changes round through practically 90° when venting is taken into account.

As the resultant pressures are such that, if no venting is taken into account, there is as a rule a tendency for the slot to open too early, it is preferable that the slot be vented at the rear to ensure correct opening.

If instead of taking the position and direction of these resultant forces on the forward aerofoil they be plotted as acting through a fixed pole, the magnitude and direction of the resultant forces lie on a smooth curve, as shown in Fig. 31.

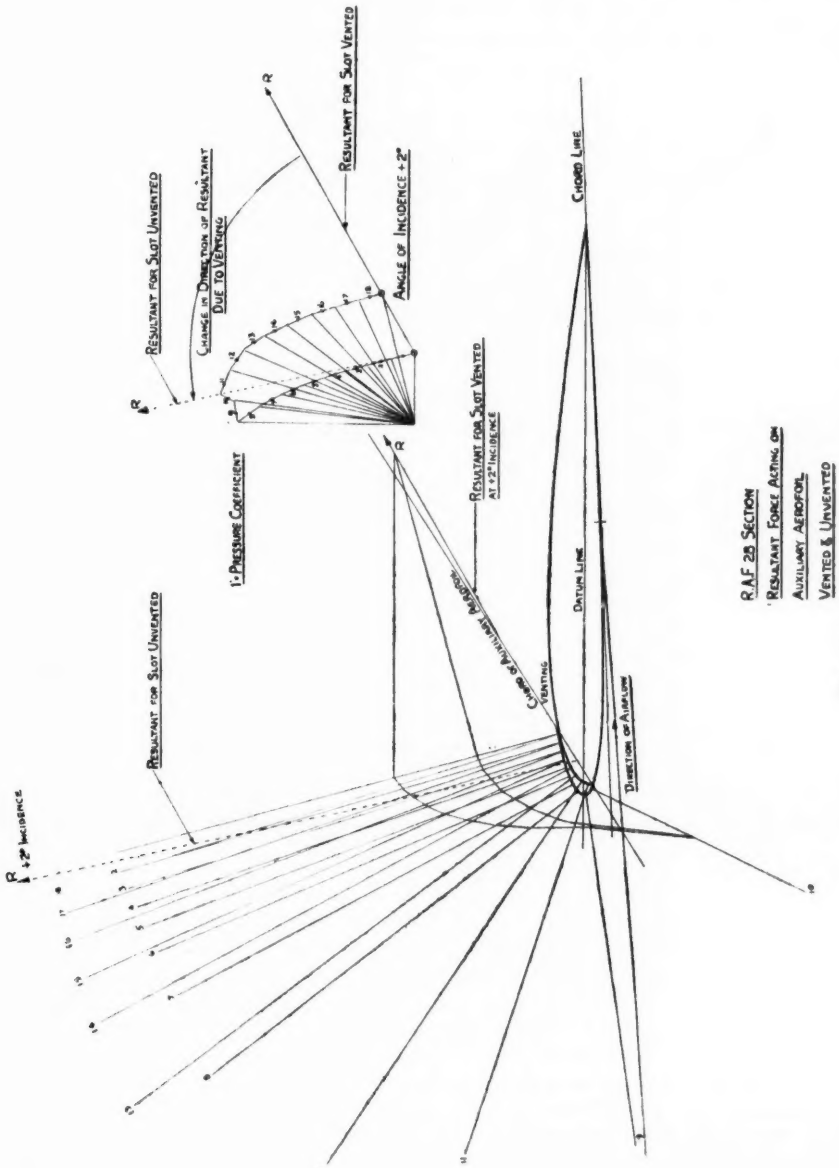

R
+2° Incidence
Resultant for Slot Unvented
1·0 Pressure Coefficient
R
Resultant for Slot Unvented
Change in Direction of Resultant Due to Venting
R
Resultant for Slot Vented
Angle of Incidence + 2°
R
Resultant for Slot Vented
At +2° Incidence
Chord Line
Datum Line
Direction of Airflow
R.A.F. 28 Section
Resultant Force Acting on Auxiliary Aerofoil
Vented & Unvented

FIG. 30.

The change due to venting is again very evident; the change in magnitude as well as the direction of the forces being very marked. It is noteworthy, too, that the magnitude of the forces on the unvented leading aerofoil is practically as great as that of the forces acting upon the aerofoil in the open position.

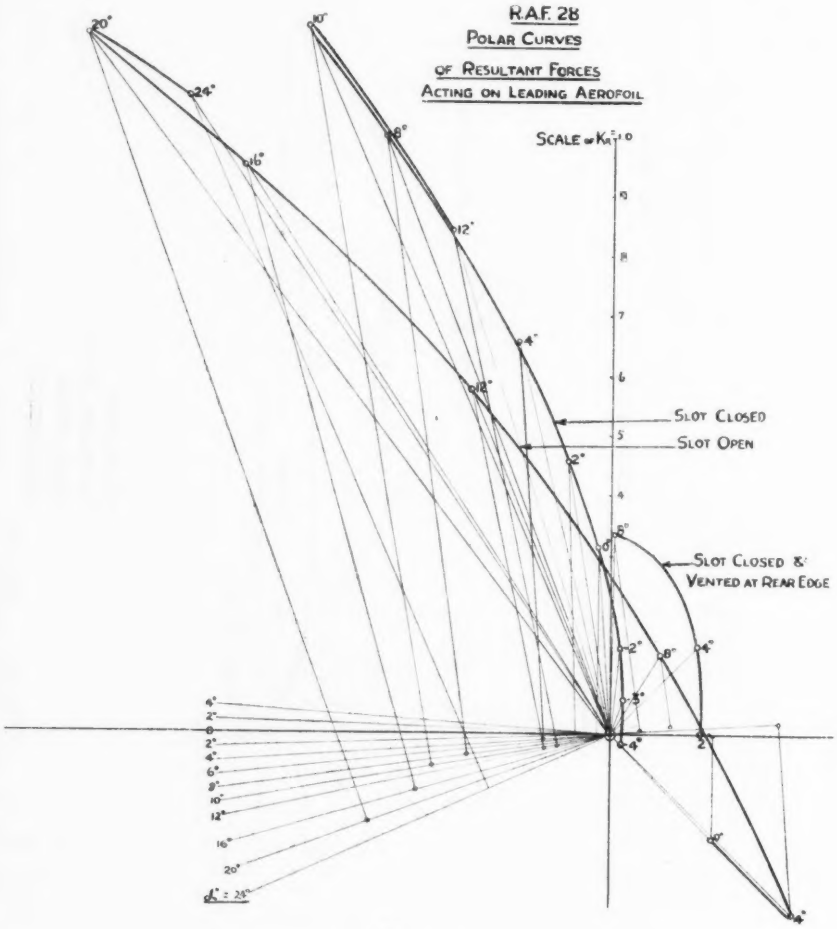
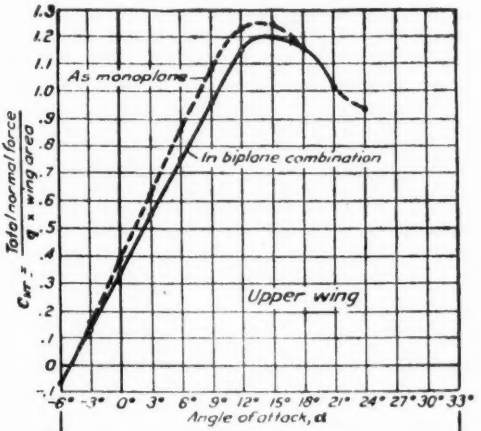


FIG. 31.

To fit the auto slot to a given section, data is essential as to the pressure distribution over the forward aerofoil, detailed in the manner shown above, so that from such information correct mechanism can be designed to permit the forward aerofoil to start moving forward at the correct angle and to move to the correct position, and so to ensure that there results an adequate increase of lift and an adequate angular range through which lift is obtained. It is not sufficient to ensure that in full-scale the slot opens at the correct angle, or to what appears to be a sufficient distance forward. It is essential that a slot shall



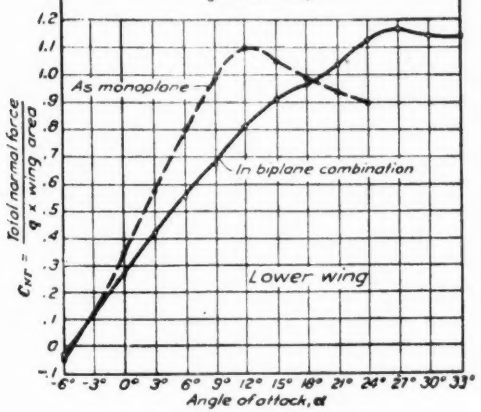


FIG. 12.—Normal force coefficient for wing

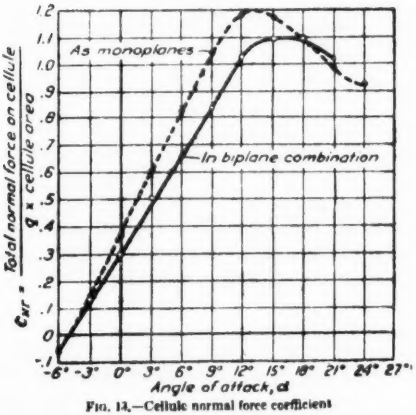

As monoplanes
In biplane combination
$C_{NF} = \frac{\text{Total normal force on cellule}}{q \times \text{cellule area}}$
Angle of attack, α

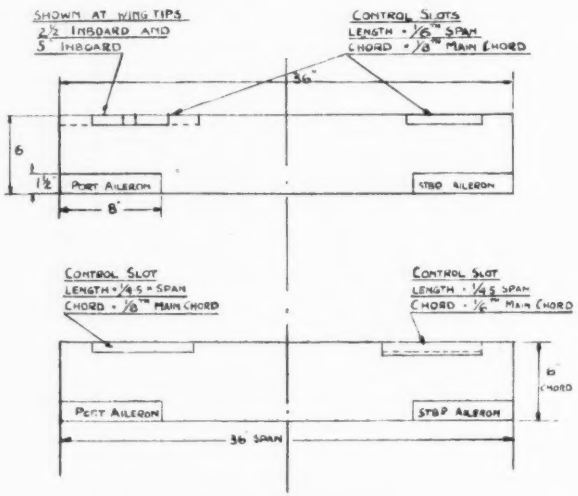
FIG. 13.—Cellule normal force coefficient

FIG. 32.

be formed when the aerofoil moves forward, so that the requisite lift conditions are present at the wing tips when the rest of the wing is stalled.

In the application of the automatic slot for control purposes the forward aerofoil is used for a portion of the wing span only. It need also only be fitted to the upper plane in a biplane arrangement.

It is well known that the lower plane continues lifting to a considerably larger angle than the top plane, particularly in the case of a biplane with forward stagger, or where there is a sesqui-plane arrangement. Thus, in Fig. 32,* the difference in the stalling angle of a wing section is shown to be greatly different, according to whether it is the upper or lower plane that is under consideration. As it is improbable that even in an involuntary stall, the high



RAF 28 SECTION

MODEL USED FOR LATERAL CONTROL TESTS

FIG. 33.

angles of incidence will be reached at which the lower plane stalls, the use of the slot on the lower plane does not appear to be warranted in the ordinary type of biplane arrangement.

With the fitting of the slot to a portion only of the wing span it by no means follows that what is correct for an auxiliary aerofoil of length equal to the wing span is correct when a portion only is used. Questions are immediately raised in designers' minds as to the proper chord, span and position of the forward aerofoil for best results.

To obtain some data on these problems a series of tests were carried out in our wind tunnel on a model 36in. by 6in. of R.A.F. 28 section. For the purposes of this test, three sets of forward aerofoils were taken as follows (see Fig. 33):—

* N.A.C.A. Report No. 271, Figs. 12 and 13.

1. Chord of aerofoil $\frac{1}{8}$th of main plane chord.
   Span of aerofoil $\frac{1}{6}$th of the span.
2. Chord of aerofoil $\frac{1}{8}$th of main plane chord.
   Span of aerofoil 1/4.5 of the main span.
3. Chord of aerofoil $\frac{1}{6}$th of main plane chord.
   Span of aerofoil 1/4.5 of the main span.

With the first two arrangements, rolling and yawing moments were measured with the ailerons set at $\pm 10°$ and $\pm 20°$, and these moments measured for three positions of the forward aerofoil as follows:—

(*a*) At the wing tips.
(*b*) With the outer edge 2½in. from the wing tips.
(*c*) With the outer edge 5in. from the wing tips.

These arrangements of forward aerofoil are shown diagrammatically in Fig. 33.

Measurements of lift coefficient gave little indication of the relative value of the different arrangements (see Fig. 34), but there were great differences in the values of rolling and yawing moments with different aileron settings.

In the case of the large span, large chord forward aerofoil, the rolling and yawing moments were measured only at the midway position, namely, with the outer end of the forward aerofoil 2½in. from the wing tip. In each case measurements were taken (1) with slots closed, (2) both slots open, and (3) with one slot closed, the last case being that in which a controlled type of forward aerofoil is used.

The object of these tests was to determine whether improved results would follow from a larger size forward aerofoil than that now used, whether and how much increased control would be obtained from a controlled slot, and further whether by placing the aerofoil more toward the centre of the wing improved control would result. It may be argued that as the breakdown of air flow starts at the central portion of the wing and proceeds outward to the tips, an aerofoil placed inboard from the tips would prevent the breakdown of the flow over a larger area of wing.

The results of these tests are shown diagrammatically in Figs. 35 to 58.

Full details of each set of measurements are given in the curves, and these have been collected for comparison purposes in Figs. 49 to 56 inclusive.

The best results in detail are as follows:—

Fig.	Position of Aerofoil.	Aerofoil span.	Aerofoil chord.	Aileron setting.
35	At extreme tips	$\frac{1}{6}$ wing span	$\frac{1}{8}$ wing chord	± 10
36	2½in. inboard from wing tips	,,	,,	,,
37	5in. inboard from wing tips	,,	,,	,,
38	At extreme tips	1/4.5 wing span	,,	,,
39	2½in. inboard from wing tips	,,	,,	,,
40	5in. inboard from wing tips	,,	,,	,,
41	At extreme tips	$\frac{1}{6}$ wing span	,,	± 20
42	2½in. inboard from wing tips	,,	,,	,,
43	5in. inboard from wing tips	,,	,,	,,
44	At extreme tips	1/4.5 wing span	,,	,,
45	2½in. inboard from wing tips	,,	,,	,,
46	5in. inboard from wing tips	,,	,,	,,
47	2½in. inboard from wing tips	,,	$\frac{1}{8}$ wing chord	± 10
48	,, ...	,,	,,	± 20

Fig.	Comparison between	Aerofoil position.	Slot position.	Aileron setting.
49	Short and long span aerofoils of small chord	At wing tips	Both open	±10° & ±20°
50	,,	2½in. inboard from wing tips	,,	,,
51	,,	5in. inboard from wing tips	,,	,,
52	,,	At wing tips	Starboard slot open only	,,
53	,,	2½in. inboard from wing tips	,,	,,
54	,,	5in. inboard from wing tips	,,	,,
55	Small and large chord aerofoils of long span	2½in. inboard from wing tips	Both open	,,
56	,,	,,	Starboard slot open only	,,

If we compare the results of Figs. 35 to 37 and 41 to 43, we see that as the forward aerofoil is moved inboard from the tips so do the rolling and yawing movements improve from a control point of view and show at the 5in. inboard position almost as good a result as the mechanically operated auto-slot control, where the one slot is closed by the upward movement of the aileron. Particularly is this the case in Fig. 43 where the results are given for ailerons at ±20° with the tip of the forward aerofoil 5in. or say 1/7in. span inboard from the main wing tips.

With the long span front aerofoil the same comparison does not hold good (see Figs. 38-40 and 44-46) the controlled slot showing a marked advantage.

When the long span aerofoils are directly compared with those of the short span (Figs. 49 to 54) the control seems worse with the larger span with both slots open, and there seems little to recommend the longer span with the mechanically operated auto-slot with one slot closed (see Figs. 52 to 54).

With the larger chord aerofoil there is, as was to be expected, again an increase in rolling moment with the ailerons at ±20°, but none with ailerons at ±10°. Figs. 55 and 56 show the comparison between the small and large chord aerofoil results. The improvement in yawing moment at high angles of incidence is particularly to be noted with the controlled slot. Here again the comparison must be qualified by referring to the changed conditions which occur in a roll.

The actual size of aerofoil chord decided upon, for any given design, will depend very largely upon the tail controls of the aeroplane for which the slot is required. Obviously, a machine which has much quicker controls and can be put into a much smaller circle will require more slot effect than one in which the machine can only be moved slowly. The above curves show the magnitude of the variations which will be obtained by change in size and position of the forward aerofoil.

The main feature of these tests with both slots open is the improvement which results from fitting the forward aerofoil inboard from the main wing tips, and in this position the remarkable increase in rolling moment as compared with the unslotted section.

It is obvious that the best improvement in control will in all cases be obtained with the arrangement in which the slot is closed or its effect neutralised on one side of the wings by the upward movement of the aileron. Such an arrangement gives at large angles of incidence a yawing moment of the right sign.

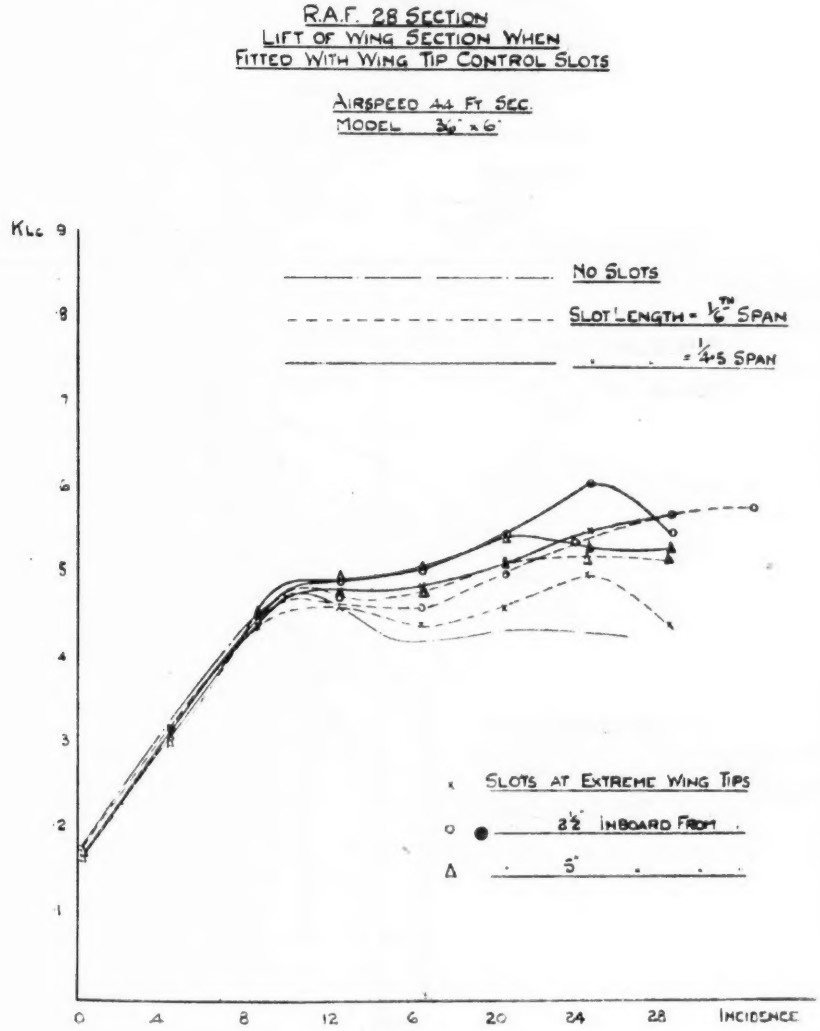

R.A.F. 28 SECTION
LIFT OF WING SECTION WHEN
FITTED WITH WING TIP CONTROL SLOTS
AIRSPEED 44 FT SEC.
MODEL 3/16" x 6"
KLc 9
8
7
6
5
4
3
2
1
NO SLOTS
SLOT LENGTH = 1/6TH SPAN
= 1/4.5 SPAN
SLOTS AT EXTREME WING TIPS
8 1/2" INBOARD FROM
5"
0
4
8
12
16
20
24
28
INCIDENCE

FIG. 34.

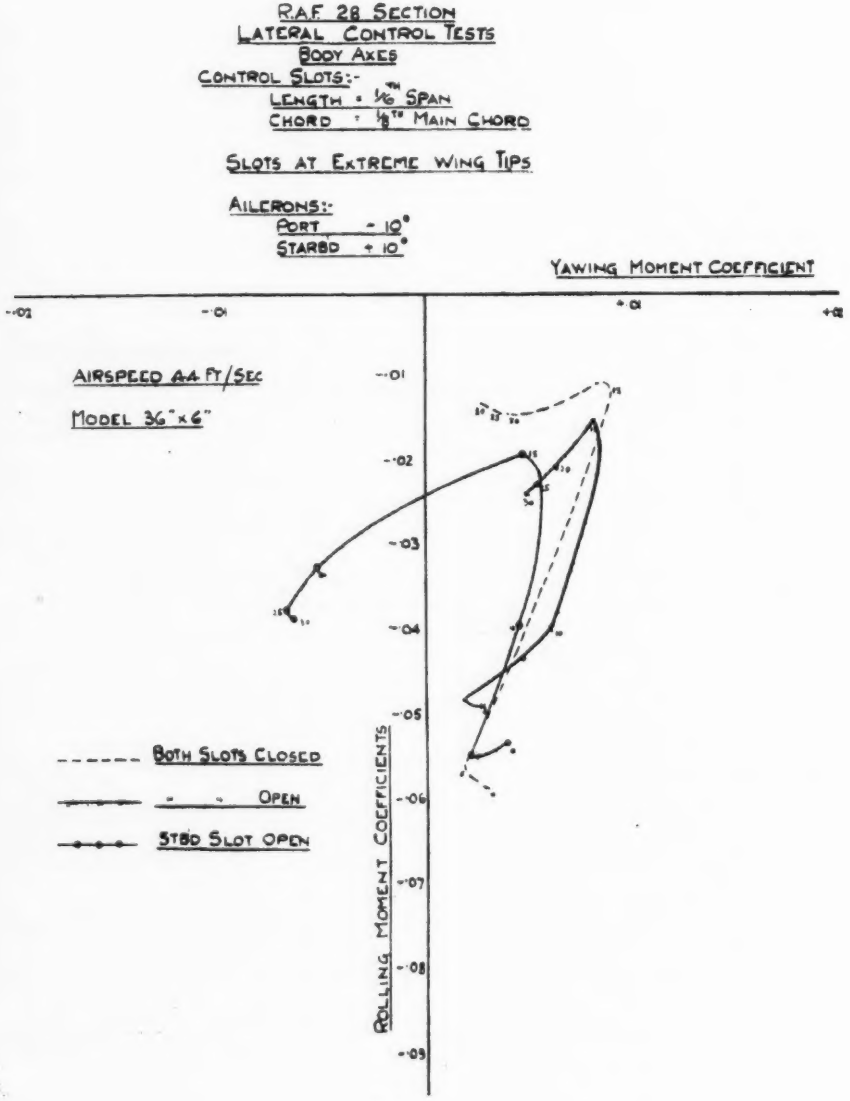

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS:-
LENGTH = 1/6TH SPAN
CHORD = 1/8TH MAIN CHORD
SLOTS AT EXTREME WING TIPS
AILERONS:-
PORT - 10°
STARBD + 10°
YAWING MOMENT COEFFICIENT
-02
-01
+01
+02
AIRSPEED 44 FT/SEC
MODEL 36"×6"
-01
-02
-03
-04
-05
-06
-07
-08
-09
ROLLING MOMENT COEFFICIENTS
BOTH SLOTS CLOSED
OPEN
STBD SLOT OPEN

FIG. 35.

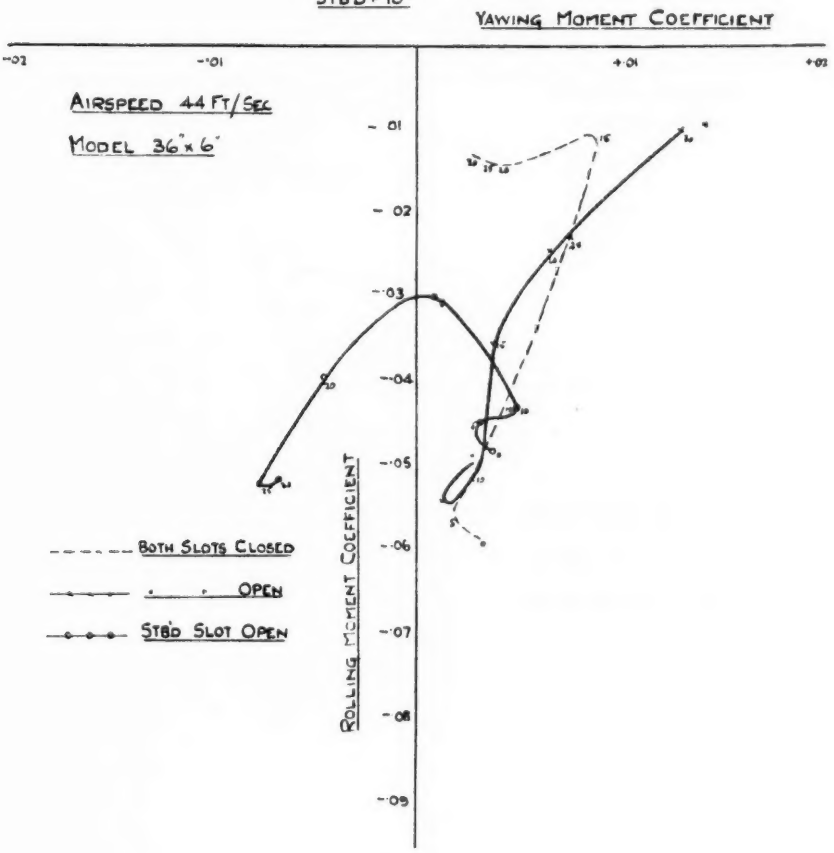

R.A.F. 28. SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS
LENGTH = 1/6TH SPAN
CHORD = 1/8TH MAIN CHORD
SLOTS 2½" FROM WING TIPS INBOARD
AILERONS
PORT - 10°
STBD + 10°
YAWING MOMENT COEFFICIENT
-·02
-·01
+·01
+·02
AIRSPEED 44 FT/SEC
MODEL 36"x6"
- 01
- 02
-·03
-·04
-·05
-·06
-·07
-·08
-·09
ROLLING MOMENT COEFFICIENT
BOTH SLOTS CLOSED
OPEN
STBD SLOT OPEN

FIG. 36.

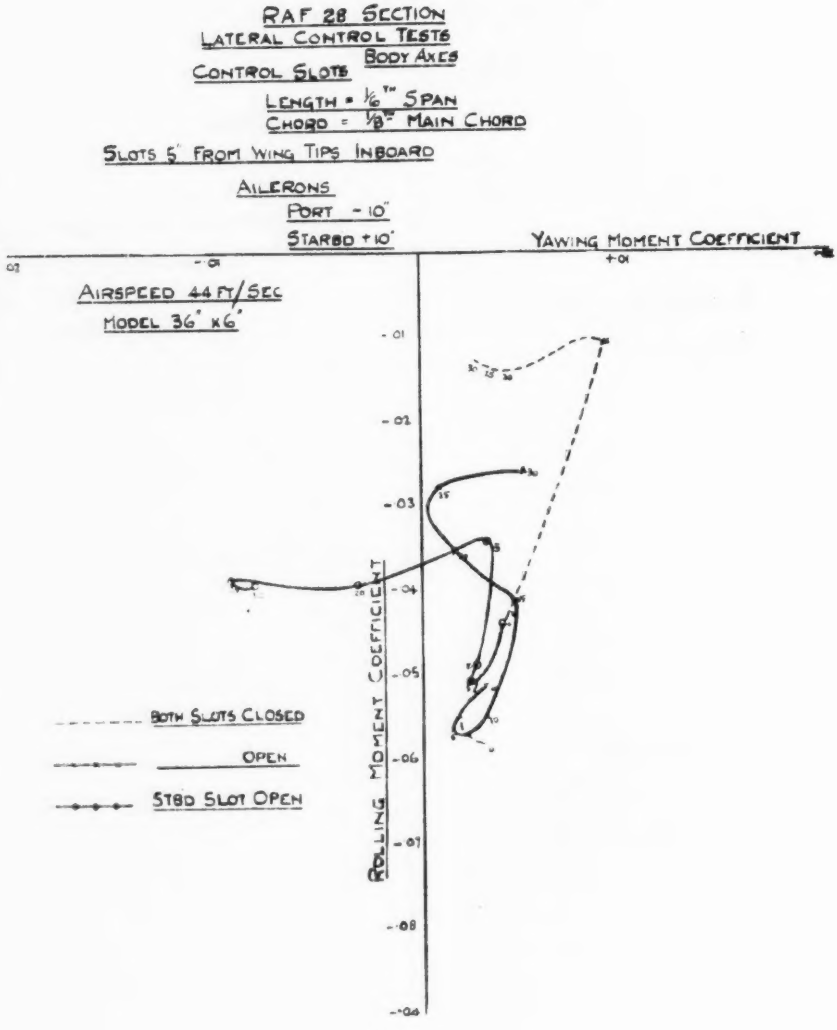

RAF 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS
LENGTH = 1/6 SPAN
CHORD = 1/8 MAIN CHORD
SLOTS 5" FROM WING TIPS INBOARD
AILERONS
PORT - 10°
STARBD + 10°
YAWING MOMENT COEFFICIENT
-01
+01
AIRSPEED 44 FT/SEC
MODEL 36" x 6"
ROLLING MOMENT COEFFICIENT
-01
-02
-03
-04
-05
-06
-07
-08
-09
BOTH SLOTS CLOSED
OPEN
STBD SLOT OPEN

FIG. 37.

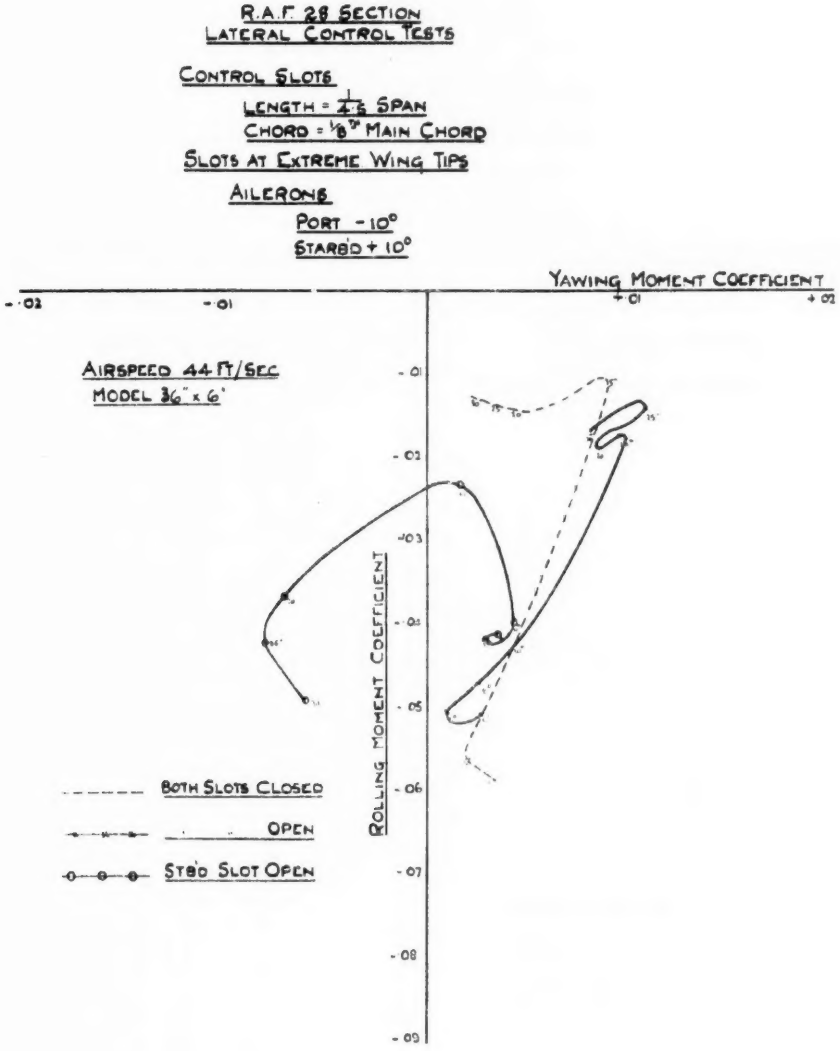

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
CONTROL SLOTS
LENGTH = 1/5 SPAN
CHORD = 1/8" MAIN CHORD
SLOTS AT EXTREME WING TIPS
AILERONS
PORT -10°
STARBD +10°
YAWING MOMENT COEFFICIENT
-·02
-·01
+·01
+·02
AIRSPEED 44 FT/SEC
MODEL 36" x 6"
-·01
-·02
-·03
-·04
-·05
-·06
-·07
-·08
-·09
ROLLING MOMENT COEFFICIENT
BOTH SLOTS CLOSED
OPEN
STB'D SLOT OPEN

FIG. 38

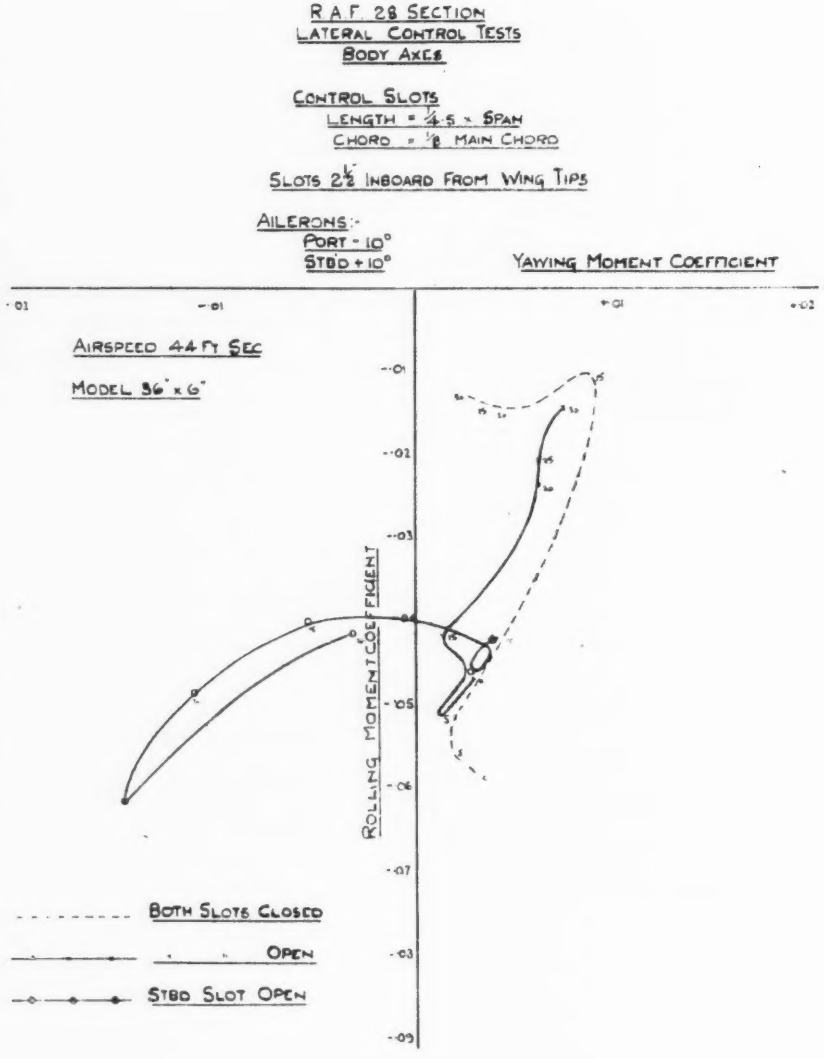

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS
LENGTH = 4.5 × SPAN
CHORD = 1/8 MAIN CHORD
SLOTS 2½' INBOARD FROM WING TIPS
AILERONS:-
PORT -10°
STBD +10°
YAWING MOMENT COEFFICIENT
·01
-·01
+·01
+·02
AIRSPEED 44 FT SEC
MODEL 36" x 6"
-·01
-·02
-·03
-·04
-·05
-·06
-·07
-·08
-·09
ROLLING MOMENT COEFFICIENT
BOTH SLOTS CLOSED
OPEN
STBD SLOT OPEN

FIG. 39

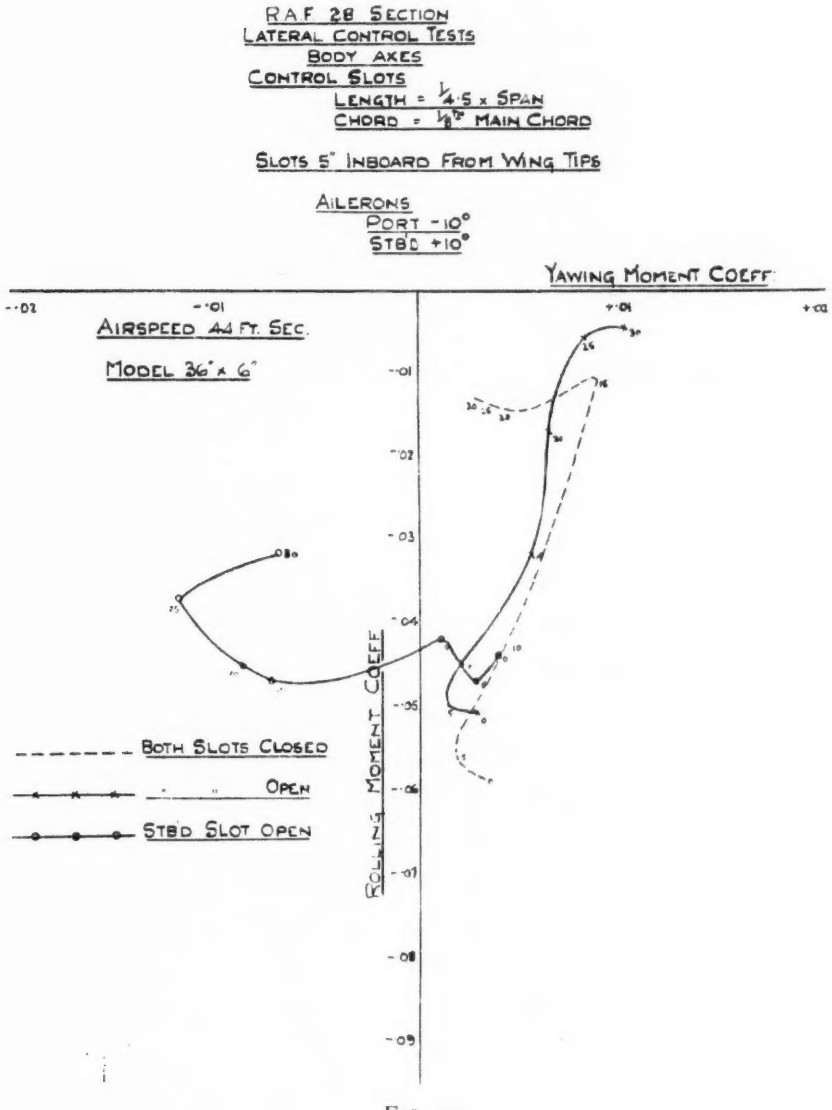

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS
LENGTH = 1/4·5 x SPAN
CHORD = 1/8 MAIN CHORD
SLOTS 5" INBOARD FROM WING TIPS
AILERONS
PORT -10°
STBD +10°
YAWING MOMENT COEFF
-·02
-·01
+·01
+·02
AIRSPEED 44 FT. SEC.
MODEL 36" x 6"
-·01
-·02
-·03
-·04
-·05
-·06
-·07
-·08
-·09
ROLLING MOMENT COEFF
BOTH SLOTS CLOSED
OPEN
STBD SLOT OPEN

FIG. 40.

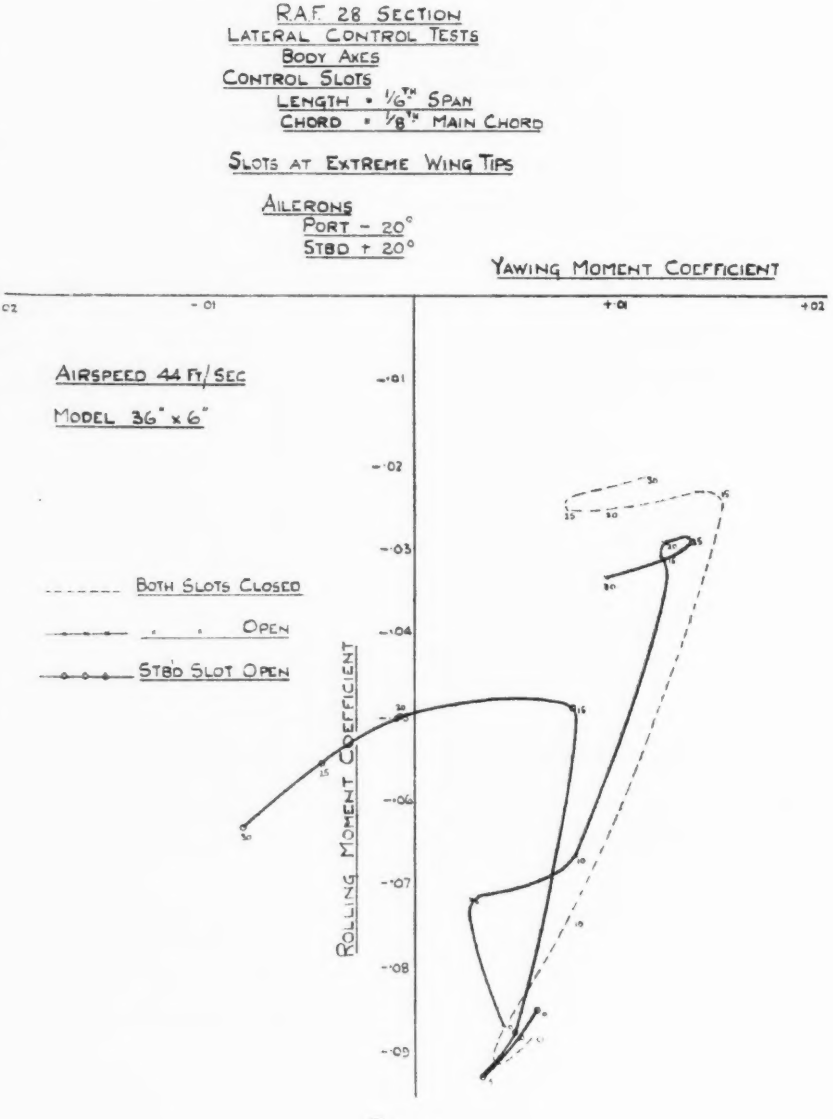

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS
LENGTH = 1/6TH SPAN
CHORD = 1/8TH MAIN CHORD
SLOTS AT EXTREME WING TIPS
AILERONS
PORT - 20°
STBD + 20°
YAWING MOMENT COEFFICIENT
-02
-01
+01
+02
AIRSPEED 44 FT/SEC
MODEL 36" x 6"
BOTH SLOTS CLOSED
OPEN
STBD SLOT OPEN
ROLLING MOMENT COEFFICIENT
-01
-02
-03
-04
-06
-07
-08
-09

FIG 41.

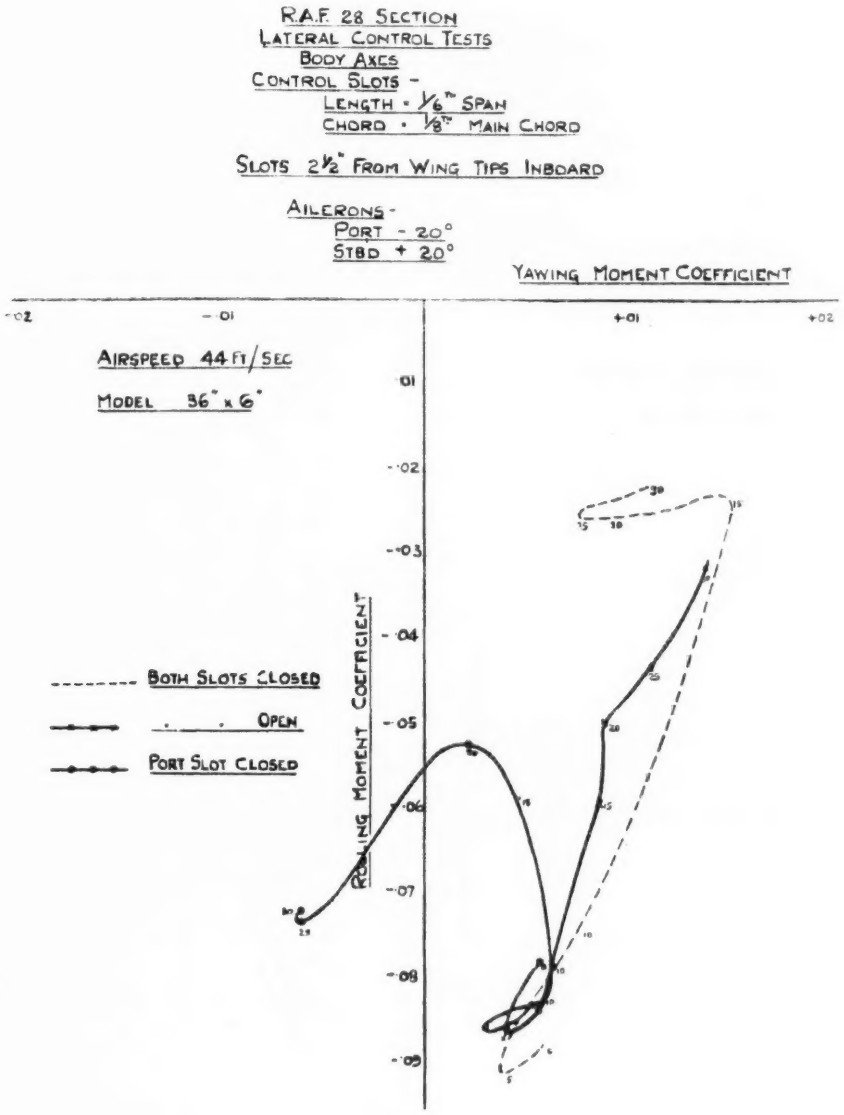

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS -
LENGTH = 1/6TH SPAN
CHORD = 1/8TH MAIN CHORD
SLOTS 2½" FROM WING TIPS INBOARD
AILERONS -
PORT - 20°
STBD + 20°
YAWING MOMENT COEFFICIENT
-02
-01
+01
+02
AIRSPEED 44 FT/SEC
MODEL 36" x 6"
-01
-02
-03
-04
-05
-06
-07
-08
-09
ROLLING MOMENT COEFFICIENT
BOTH SLOTS CLOSED
OPEN
PORT SLOT CLOSED

FIG. 42.

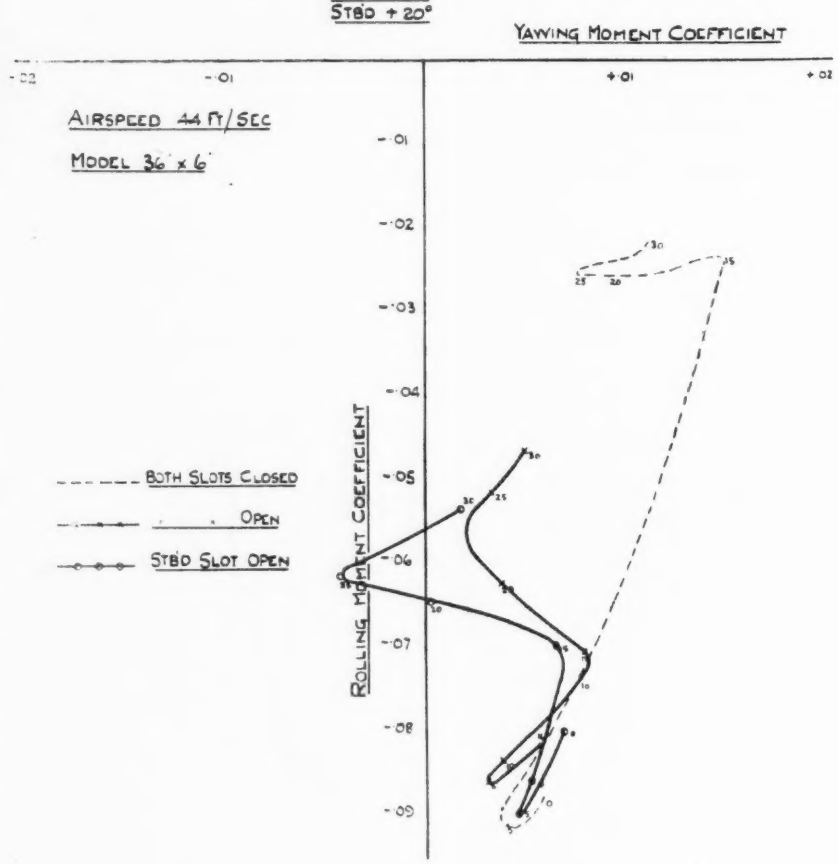

R.A.F 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS
LENGTH = 1/6TH SPAN
CHORD = 1/8TH MAIN CHORD
SLOTS 5 FROM WING TIPS INBOARD
AILERONS:-
PORT - 20°
STBD + 20°
YAWING MOMENT COEFFICIENT
-.02
-.01
+.01
+.02
AIRSPEED 44 FT/SEC
MODEL 36 x 6'
-.01
-.02
-.03
-.04
-.05
-.06
-.07
-.08
-.09
ROLLING MOMENT COEFFICIENT
BOTH SLOTS CLOSED
OPEN
STBD SLOT OPEN

FIG. 43.

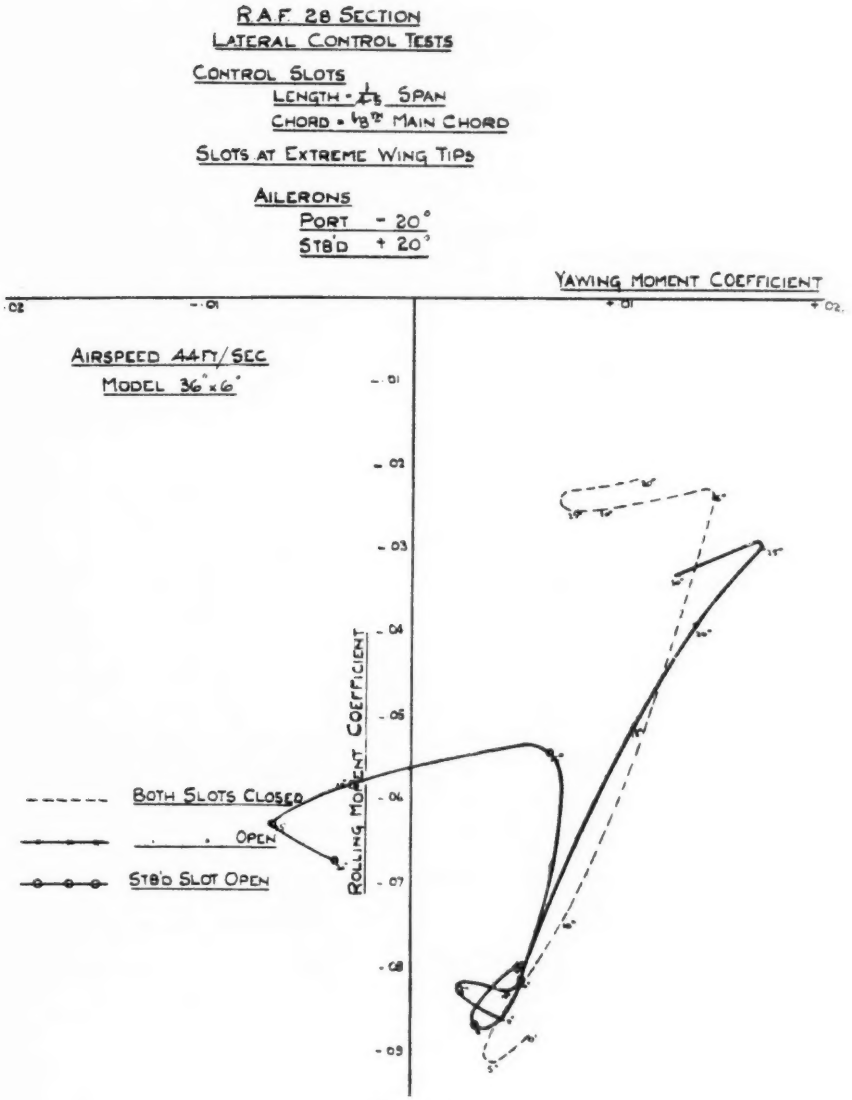

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
CONTROL SLOTS
LENGTH - 1/5 SPAN
CHORD - 1/8 MAIN CHORD
SLOTS AT EXTREME WING TIPS
AILERONS
PORT - 20°
STB'D + 20°
YAWING MOMENT COEFFICIENT
-.02
-.01
+.01
+.02
AIRSPEED 44 FT/SEC
MODEL 36"x6"
ROLLING MOMENT COEFFICIENT
-.01
-.02
-.03
-.04
-.05
-.06
-.07
-.08
-.09
BOTH SLOTS CLOSED
OPEN
STB'D SLOT OPEN

FIG. 44.

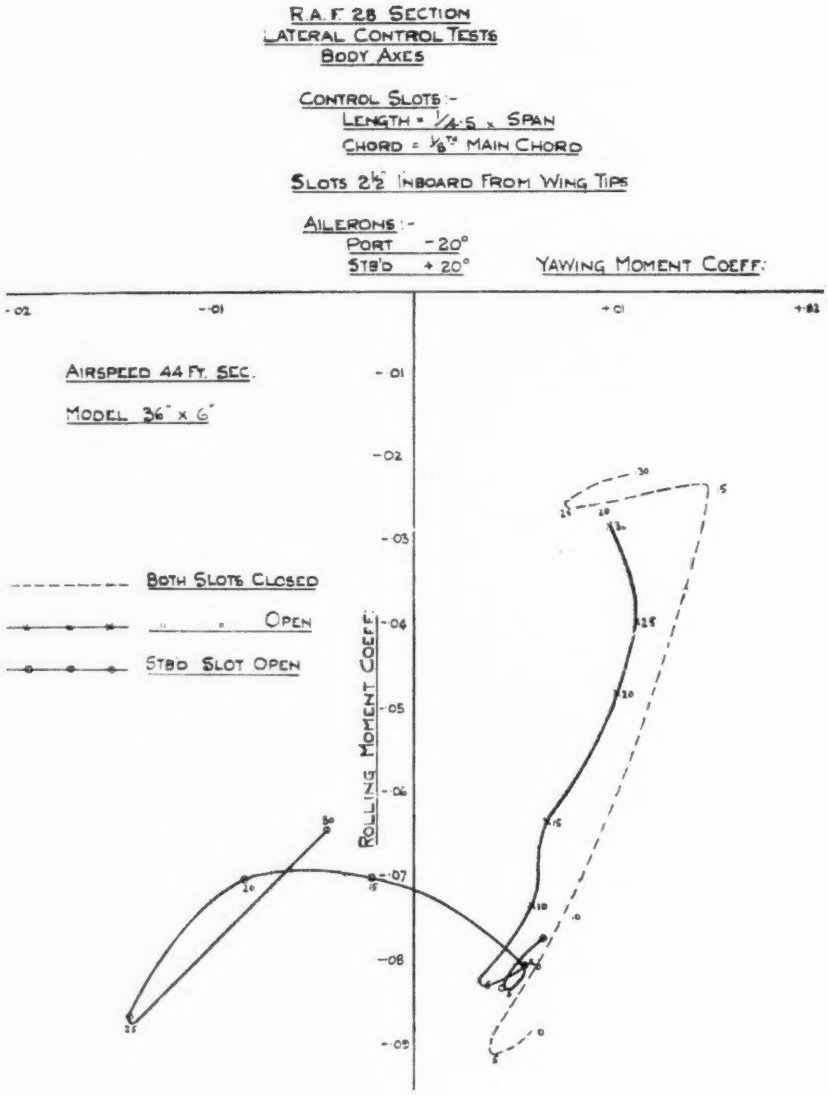

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS:-
LENGTH = 1/4·5 × SPAN
CHORD = 1/8" MAIN CHORD
SLOTS 2½" INBOARD FROM WING TIPS
AILERONS:-
PORT −20°
STB'D +20°
YAWING MOMENT COEFF:
-02
-01
+01
+02
AIRSPEED 44 FT. SEC.
MODEL 36" × 6"
BOTH SLOTS CLOSED
" " OPEN
STBD SLOT OPEN
ROLLING MOMENT COEFF:
-01
-02
-03
-04
-05
-06
-07
-08
-09

FIG. 45.

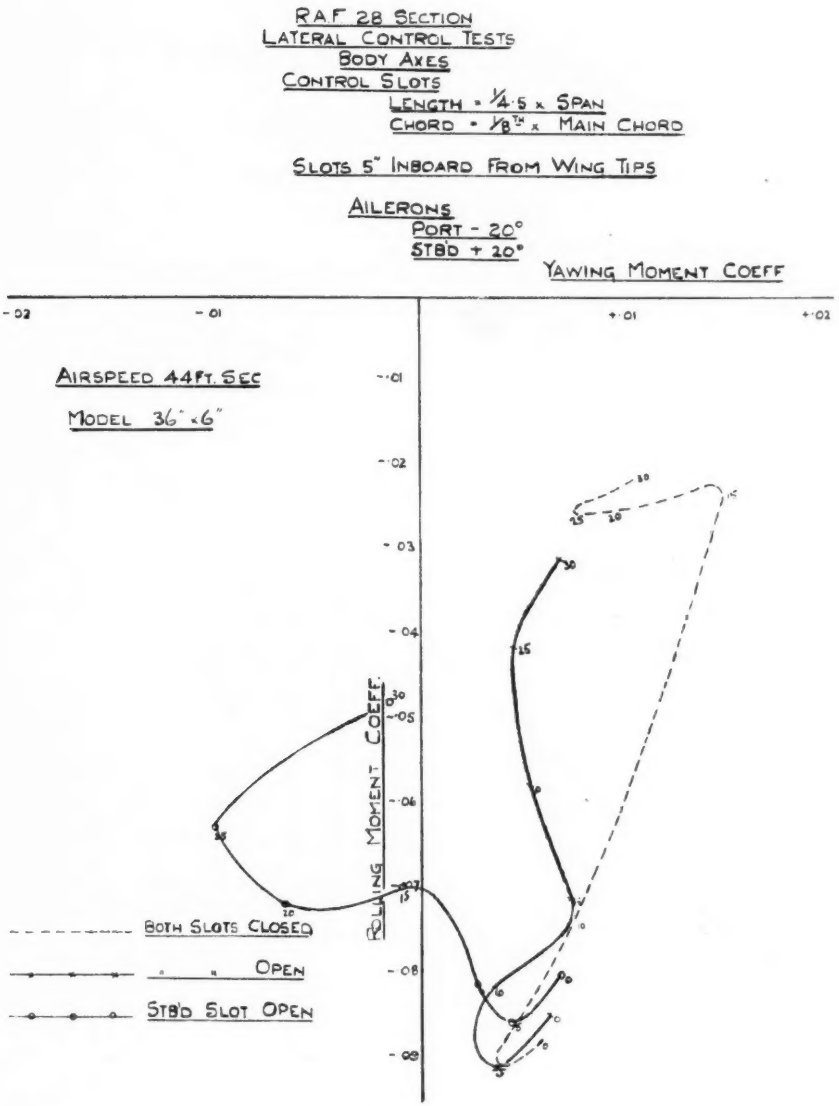

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
CONTROL SLOTS
LENGTH = 1/4·5 x SPAN
CHORD = 1/8TH x MAIN CHORD
SLOTS 5" INBOARD FROM WING TIPS
AILERONS
PORT - 20°
STB'D + 20°
YAWING MOMENT COEFF
- 02
- 01
+ 01
+ 02
AIRSPEED 44 FT. SEC
MODEL 36" x 6"
- 01
- 02
- 03
- 04
- 05
- 06
- 07
- 08
- 09
ROLLING MOMENT COEFF.
BOTH SLOTS CLOSED
OPEN
STB'D SLOT OPEN

FIG. 46.

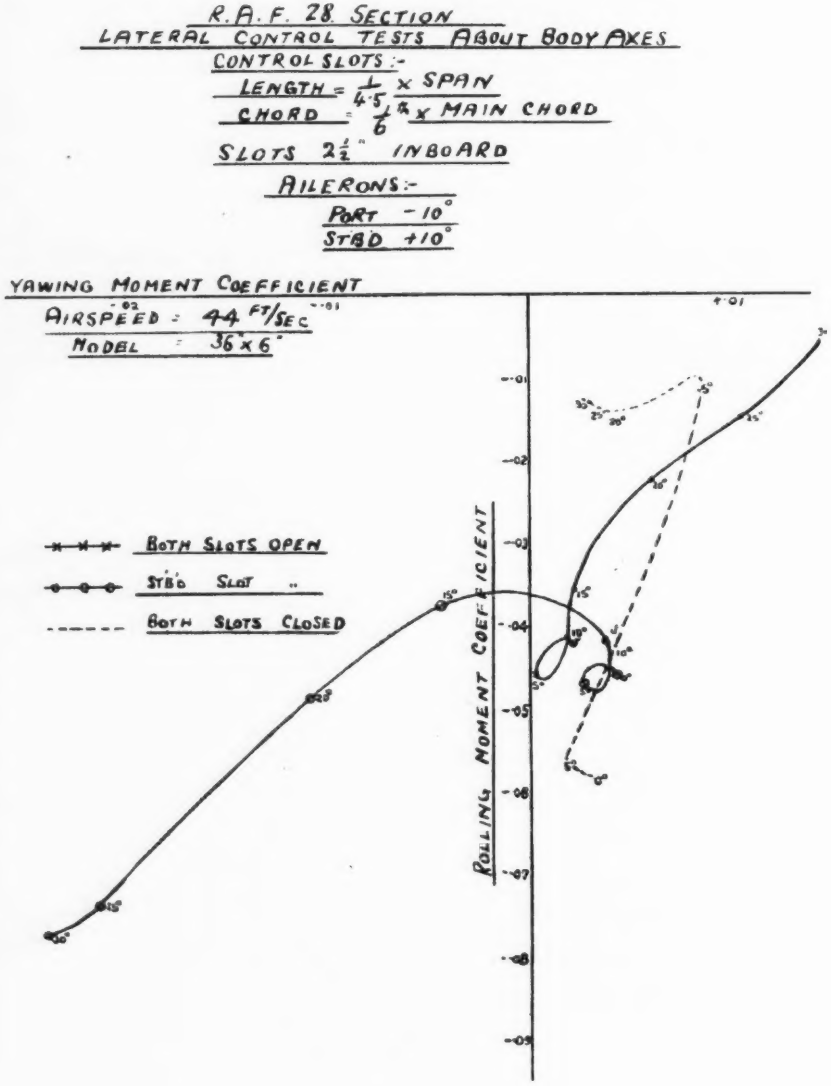

R.A.F. 28 SECTION
LATERAL CONTROL TESTS ABOUT BODY AXES
CONTROL SLOTS :-
LENGTH = 1/4.5 x SPAN
CHORD = 1/6 x MAIN CHORD
SLOTS 2½" INBOARD
AILERONS :-
PORT -10°
STBD +10°
YAWING MOMENT COEFFICIENT
AIRSPEED = 44 FT/SEC
MODEL = 36 x 6"
BOTH SLOTS OPEN
STBD SLOT ..
BOTH SLOTS CLOSED
ROLLING MOMENT COEFFICIENT
+.01
-.01
-.02
-.03
-.04
-.05
-.06
-.07
-.08
-.09

FIG. 47.

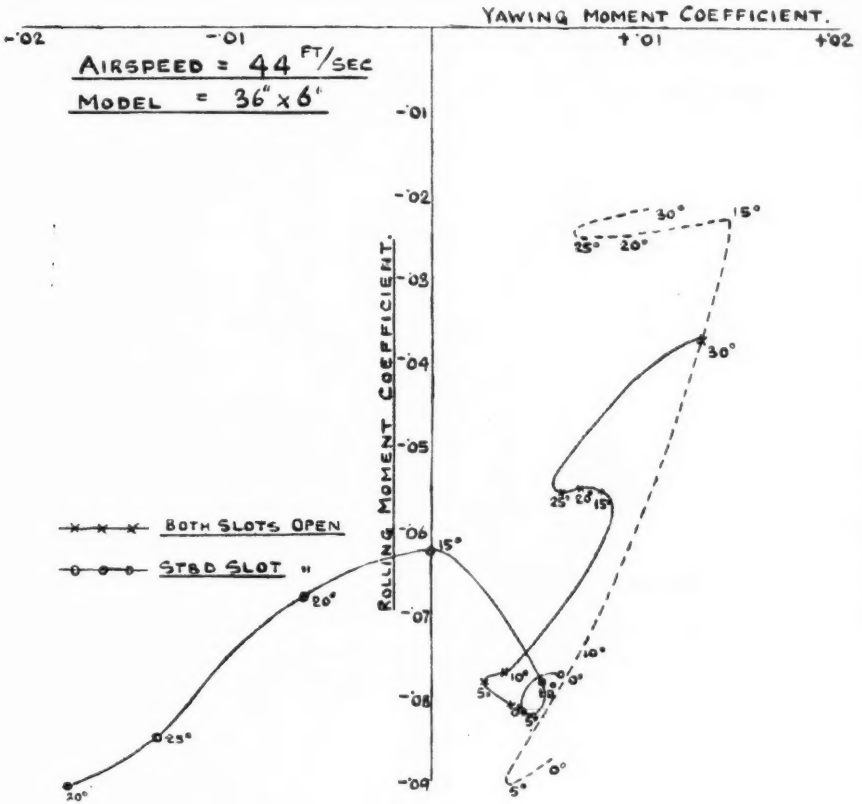

R.A.F. 28. SECTION
LATERAL CONTROL TESTS ABOUT BODY AXES
CONTROL SLOTS:-
LENGTH = 1/4.5 x SPAN
CHORD = 1/6th x MAIN CHORD
SLOTS 2½" INBOARD
AILERONS:-
PORT -20°
STB'D +20°
YAWING MOMENT COEFFICIENT.
-02
-01
+01
+02
AIRSPEED = 44 FT/SEC
MODEL = 36" x 6"
-01
-02
-03
-04
-05
-06
-07
-08
-09
ROLLING MOMENT COEFFICIENT.
BOTH SLOTS OPEN
STBD SLOT "
30°
15°
25°
20°
30°
25°
20°
15°
15°
20°
25°
20°
10°
5°
0°
10°
0°
5°
0°
5°

FIG. 48.

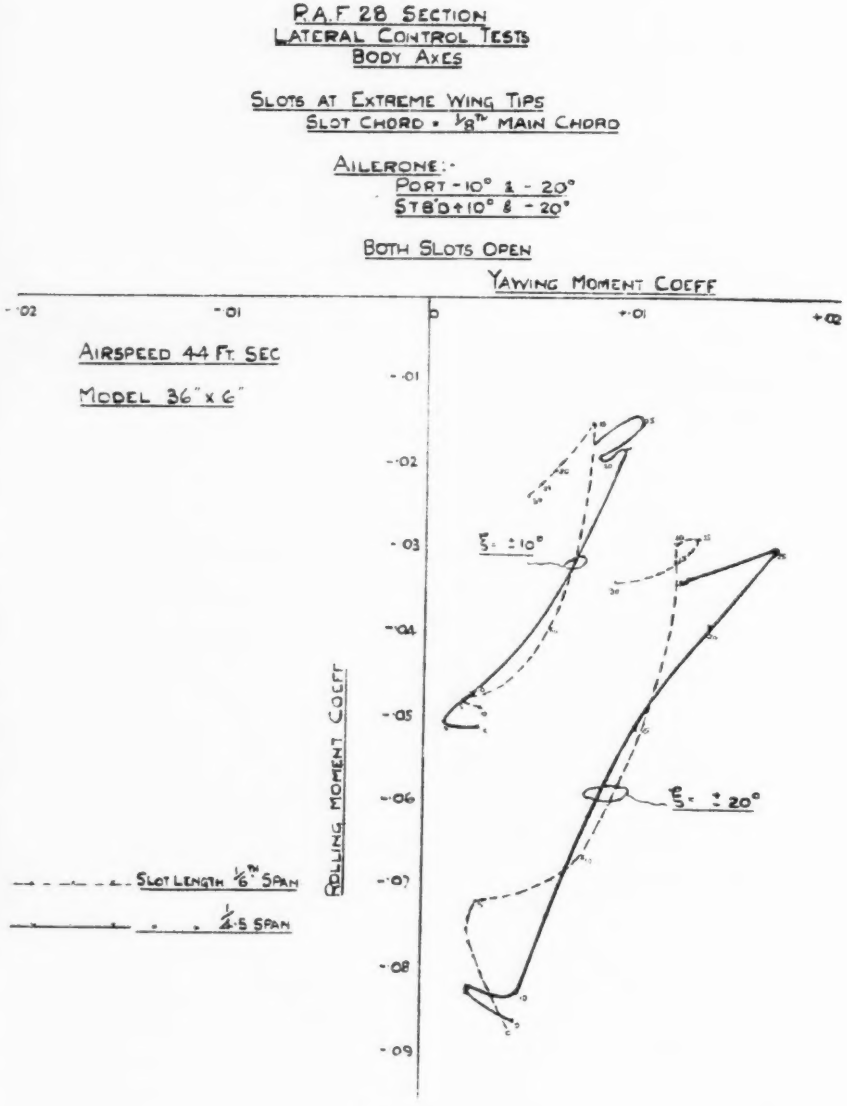

R.A.F 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
SLOTS AT EXTREME WING TIPS
SLOT CHORD = 1/8TH MAIN CHORD
AILERONE:-
PORT -10° & -20°
STBD +10° & -20°
BOTH SLOTS OPEN
YAWING MOMENT COEFF
-02
-01
0
+01
+02
AIRSPEED 44 FT. SEC
MODEL 36" x 6"
-01
-02
-03
-04
-05
-06
-07
-08
-09
ROLLING MOMENT COEFF
ξ = ±10°
ξ = ±20°
SLOT LENGTH 1/6TH SPAN
1/4·5 SPAN

FIG. 49.

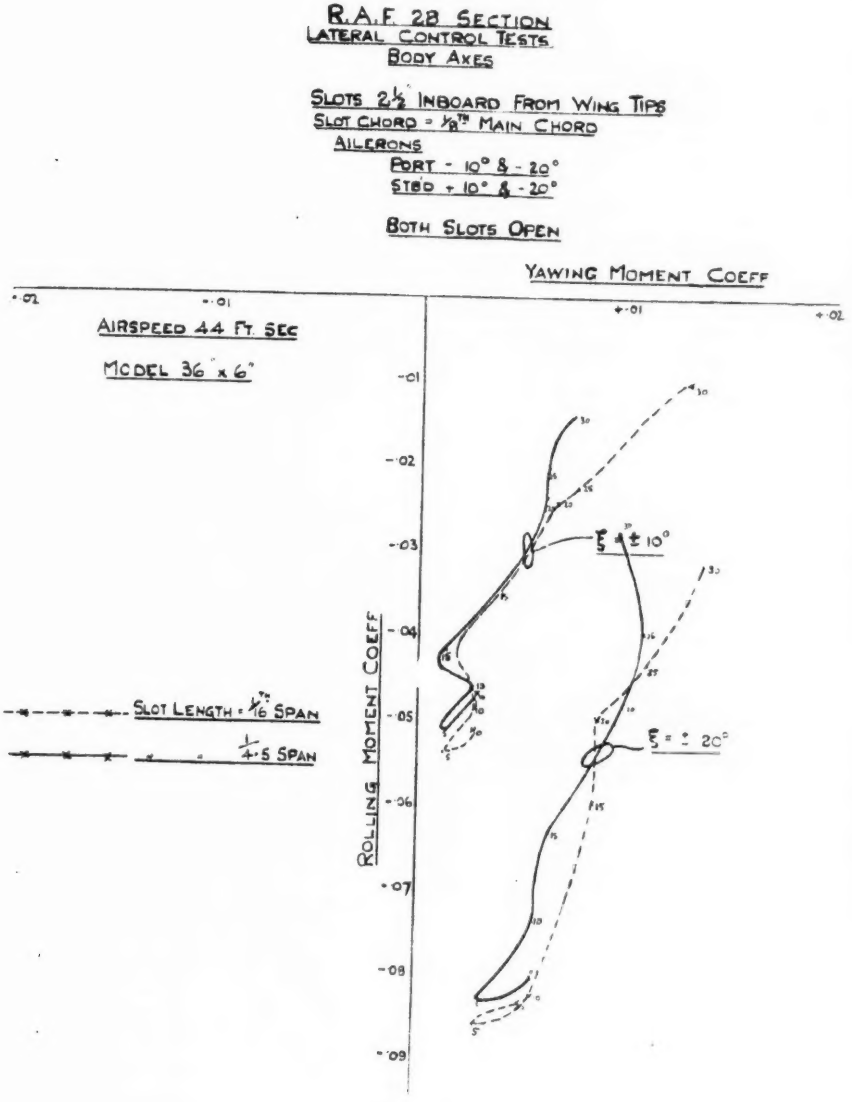

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
SLOTS 2½ INBOARD FROM WING TIPS
SLOT CHORD = 1/8TH MAIN CHORD
AILERONS
PORT - 10° & - 20°
STBD + 10° & - 20°
BOTH SLOTS OPEN
YAWING MOMENT COEFF
AIRSPEED 44 FT. SEC
MODEL 36" x 6"
ROLLING MOMENT COEFF
SLOT LENGTH = 1/16 SPAN
1/4·5 SPAN
ξ = ± 10°
ξ = ± 20°

FIG. 50.

R.A.F.28 SECTION
LATERAL CONTROL TESTS
BODY AXES

SLOTS 5" INBOARD FROM WING TIPS
SLOT CHORD = 1/8 MAIN CHORD
AILERONS
PORT -10° & -20°
STBD +10° & +20°

BOTH SLOTS OPEN

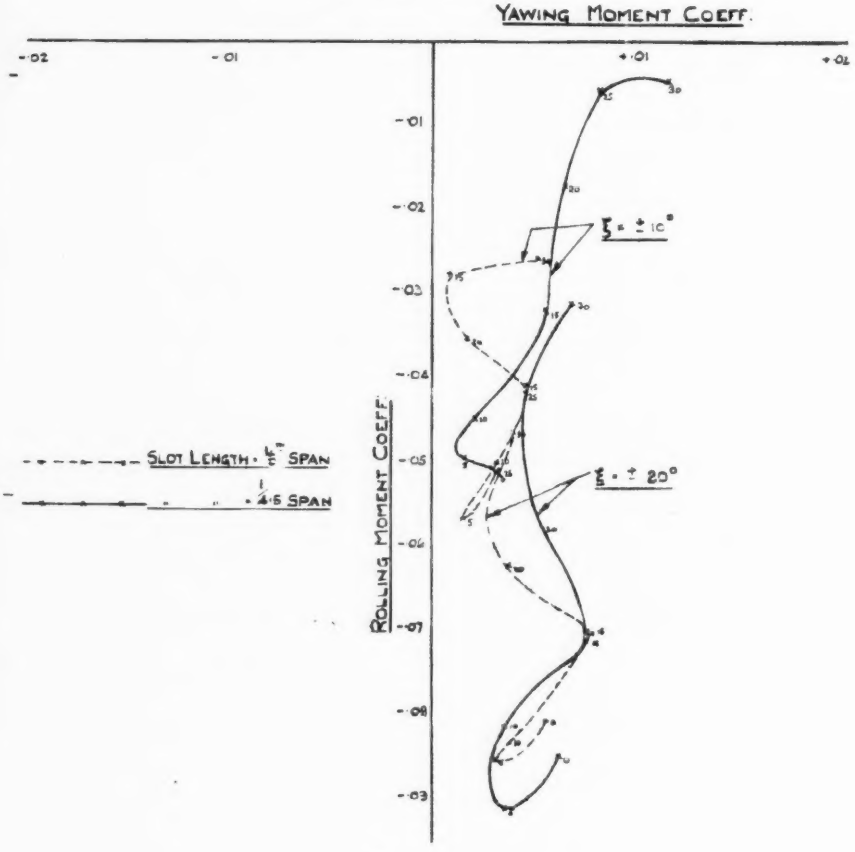


FIG. 51.

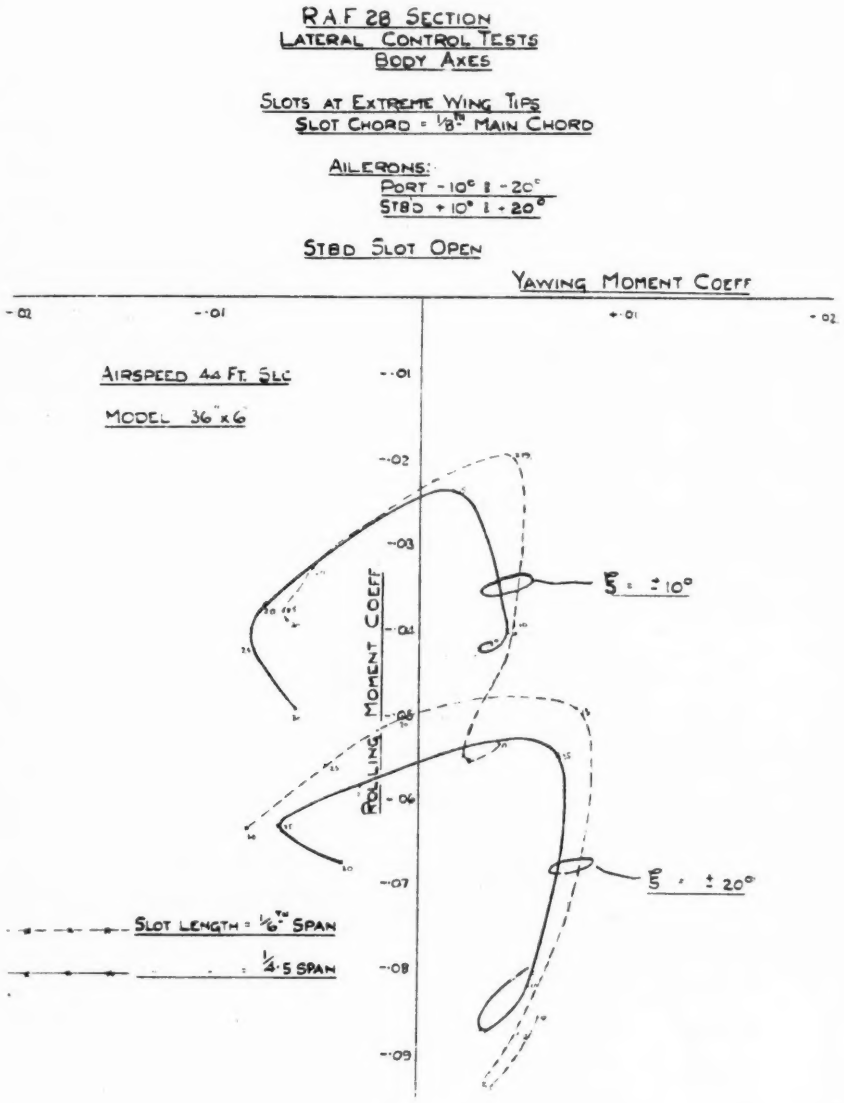

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
SLOTS AT EXTREME WING TIPS
SLOT CHORD = 1/8" MAIN CHORD
AILERONS:
PORT -10° & -20°
STBD +10° & -20°
STBD SLOT OPEN
YAWING MOMENT COEFF
-.02
-.01
+.01
+.02
AIRSPEED 44 FT. SEC
MODEL 36"x6"
-.01
-.02
-.03
-.04
-.05
-.06
-.07
-.08
-.09
ROLLING MOMENT COEFF
ξ = ±10°
ξ = ±20°
SLOT LENGTH = 1/6" SPAN
= 1/4.5 SPAN

FIG. 52.

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES

SLOTS 2½" INBOARD FROM WING TIPS
SLOT CHORD = 1/8" MAIN CHORD
AILERONS :-
PORT −10° & −20°
STB'D +10° & +20°

STB'D SLOT OPEN

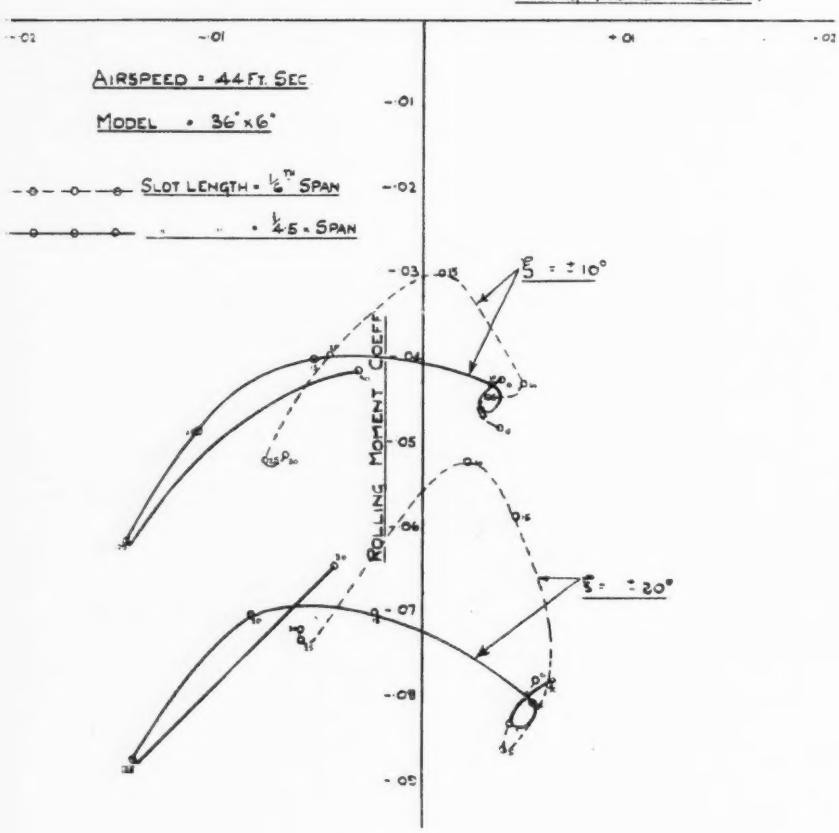


FIG. 53.

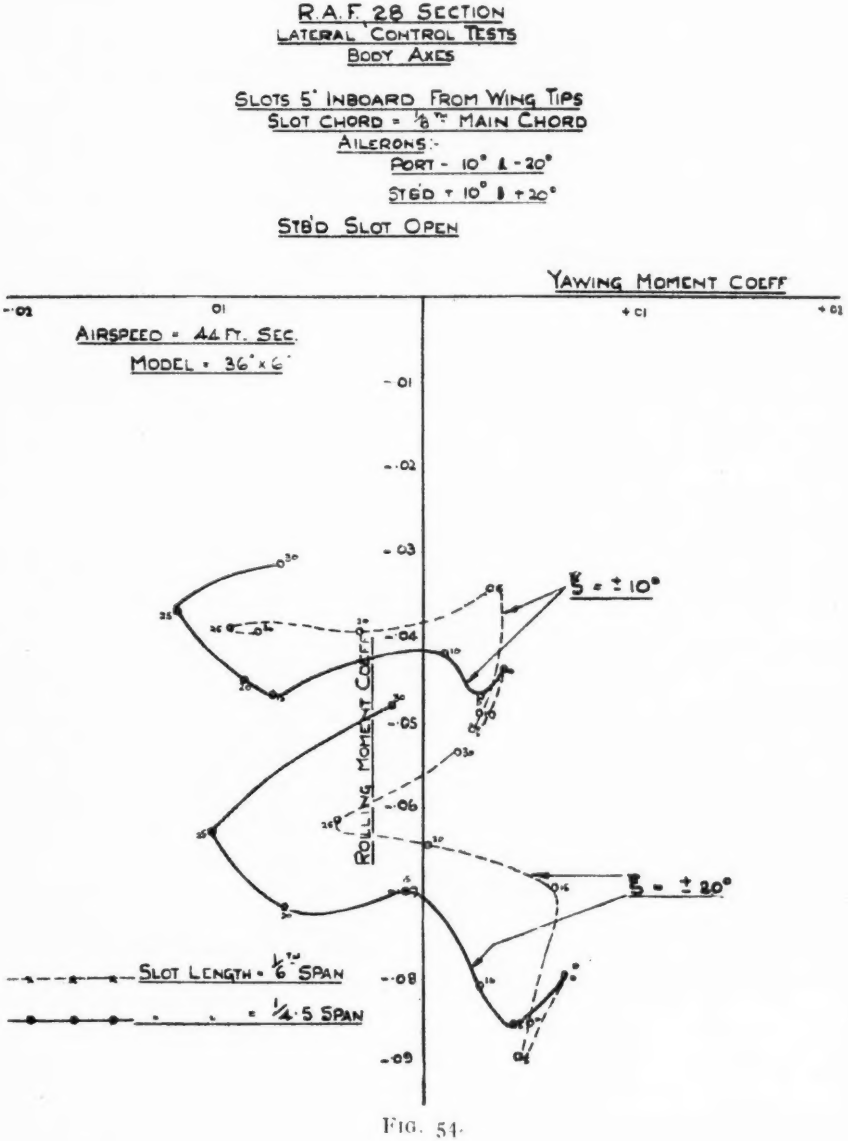

R.A.F. 28 SECTION
LATERAL CONTROL TESTS
BODY AXES
SLOTS 5° INBOARD FROM WING TIPS
SLOT CHORD = 1/8 MAIN CHORD
AILERONS:-
PORT - 10° δ - 20°
STBD + 10° δ + 20°
STB'D SLOT OPEN
YAWING MOMENT COEFF
-02
-01
+01
+02
AIRSPEED = 44 FT. SEC.
MODEL = 36" x 6"
-01
-02
-03
-04
-05
-06
-08
-09
ROLLING MOMENT COEFF
δ = ± 10°
δ = ± 20°
SLOT LENGTH = 1/6 SPAN
= 1/4·5 SPAN

FIG. 54.

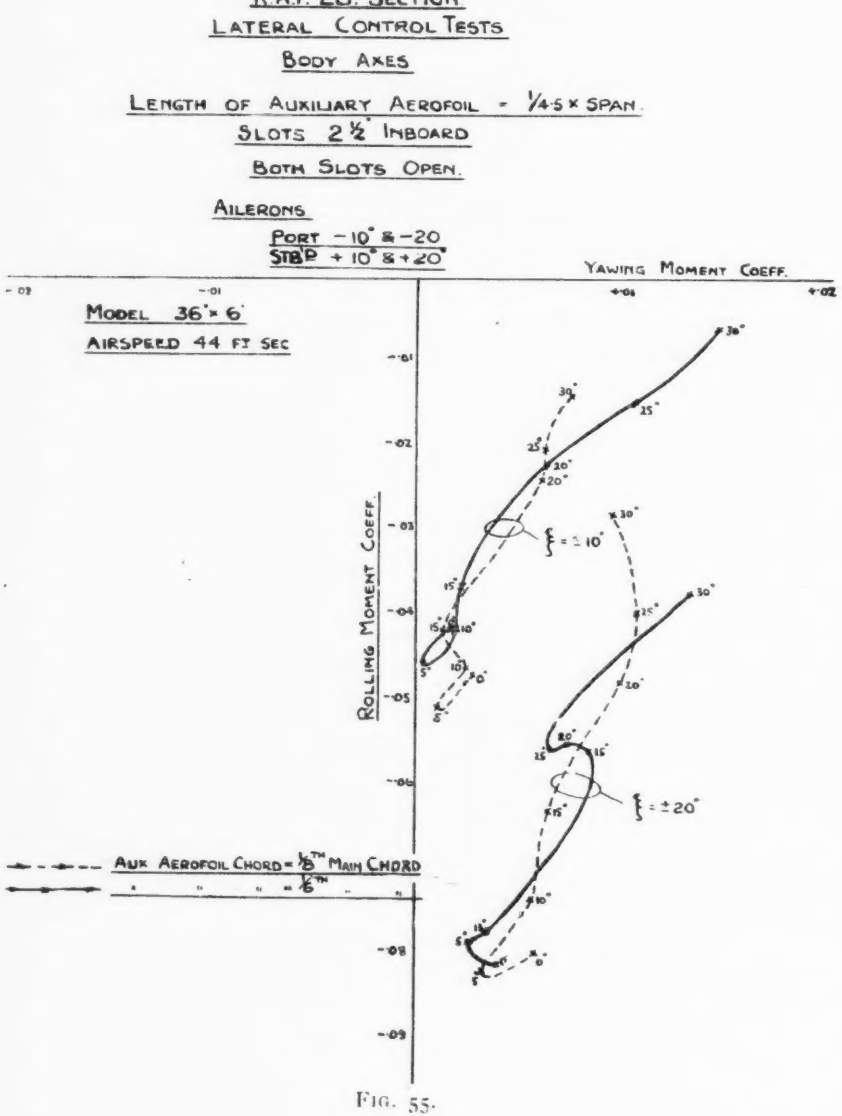

R.A.F. 28. SECTION
LATERAL CONTROL TESTS
BODY AXES
LENGTH OF AUXILIARY AEROFOIL = 1/4·5 × SPAN.
SLOTS 2½" INBOARD
BOTH SLOTS OPEN.
AILERONS
PORT −10° & −20
STBD +10° & +20°
MODEL 36" × 6"
AIRSPEED 44 FT SEC
YAWING MOMENT COEFF.
ROLLING MOMENT COEFF.
ξ = ± 10°
ξ = ± 20°
AUX AEROFOIL CHORD = 1/8TH MAIN CHORD
" " " = 1/6TH " "

FIG. 55.

R.A.F. 28. SECTION.
LATERAL CONTROL TESTS ABOUT BODY AXES.
SLOTS 2½" INBOARD.
LENGTH OF SLOT = 1/45 × SPAN.
PORT SLOT CLOSED.
AILERONS
PORT −10° & −20°.
STBD +10° & +20°

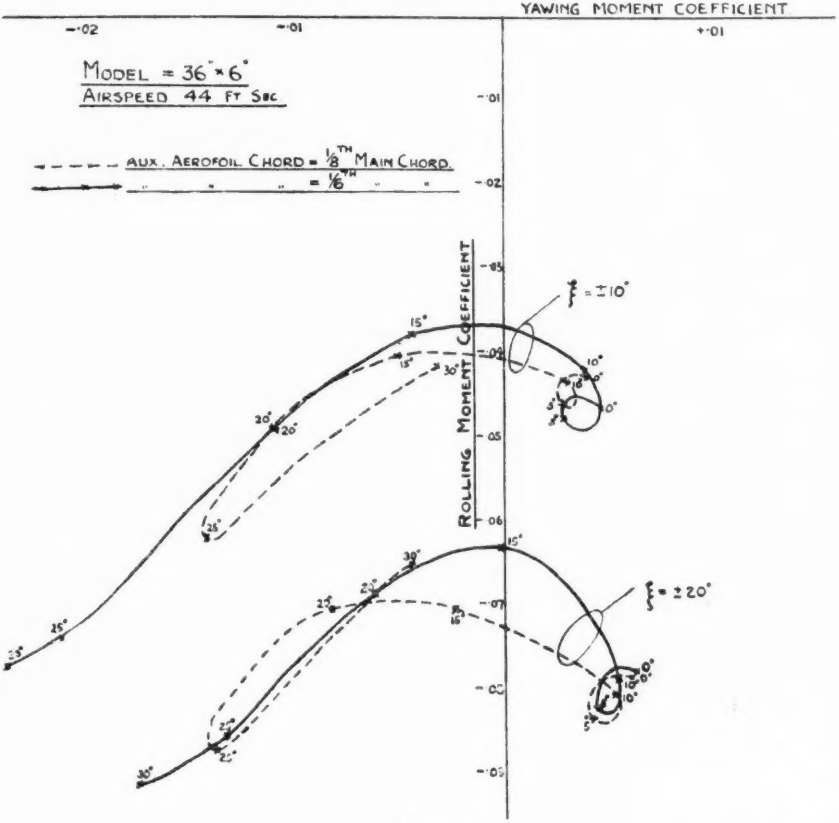
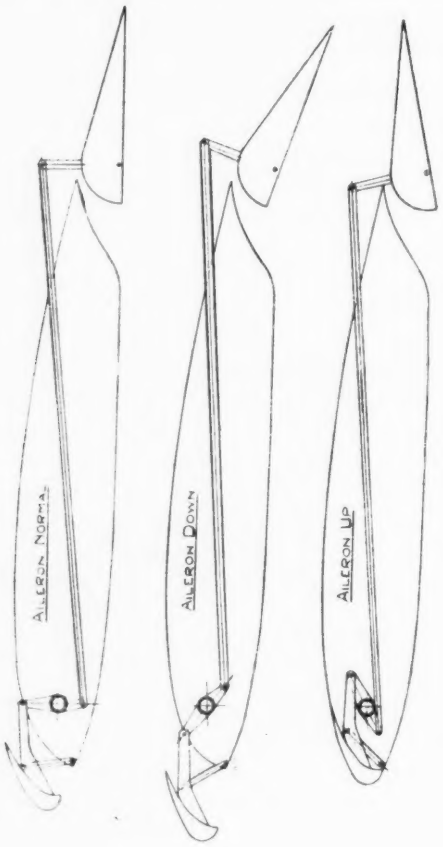


FIG. 56.

An arrangement for interlinking the slot and aileron is shown in Fig. 57, but many variations are possible, notably by the movement of the link hinge point so that a closing torque is brought into action on the forward aerofoil.

The objections to moving the forward aerofoil by hand and the complication of interconnected mechanism can be overcome by the use of an " interceptor "



SLOT AILERON INTERCONNECTION

FIG. 57.

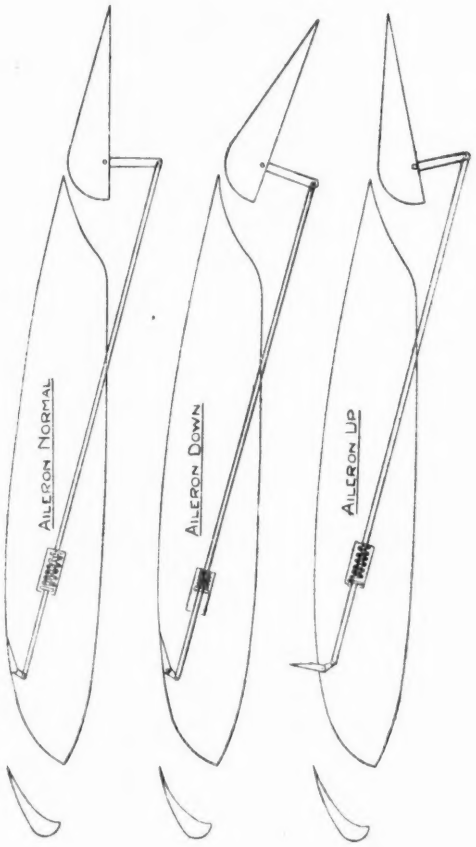
or " spoiler " (see Fig. 58). The action of this small vertical plate is to cause " burbling " in the same manner as if the slot were closed.

A comparison is given in Fig. 59 of the rolling and yawing moments on a R.A.F. 28 section for

(*a*) Both wing tip slots open without interceptor;
(*b*) Both wing tip slots open with an interceptor fitted on one side; and
(*c*) One wing tip slot closed and no interceptor fitted.

The dimensions of the interceptor are given in the illustration. The moments were measured for the ailerons at ± 10 and ± 20.

There is with the interceptor a great improvement in control over the case of both slots open and at the smaller angles (say up to 20° angle of incidence) over the case of one slot closed. Beyond this angle the rolling moments are not quite so large as with the one slot closed.



AILERON & INTERCEPTOR INTERCONNECTION
SLOT OPEN

FIG. 58.

A similar arrangement of interceptor has been tested for a complete model biplane fitted with slots along its whole span. The increase in rolling moment by its use is shown in Fig. 60. Tested in full-scale in free flight the model results are fully borne out in practice, and the control is no different in feel to the ordinary aileron and no heavier to operate.

In the tests which have been described, and the results which have been given, the forward aerofoil has been shown as part of the original wing section when the slot is closed. It is somewhat easier in construction to fit an additional forward aerofoil on the top of a normal section in the way in which a plaster is fitted. Such a slot is somewhat easier to construct for a wing section already in being, and it is easier to adapt wings that are already made to this

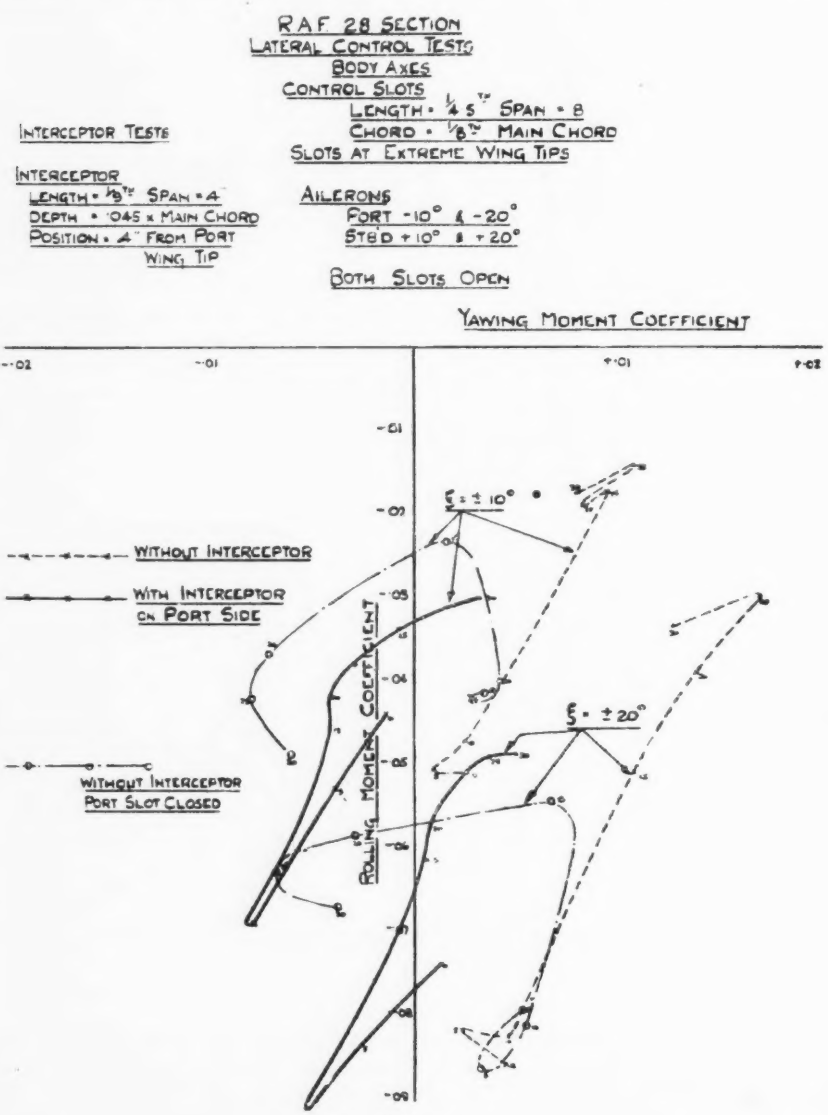


FIG. 59.

type. This variation has been developed by Mr. Bruce, of the Westland Company, and has been shown to be equally advantageous to the type of forward aerofoil forming part of the wing itself.

From an æsthetic point of view it would appear preferable to adhere to the same wing section throughout the plane, which has been chosen for its aerodynamic qualities, but if practical use shows that the same results can be

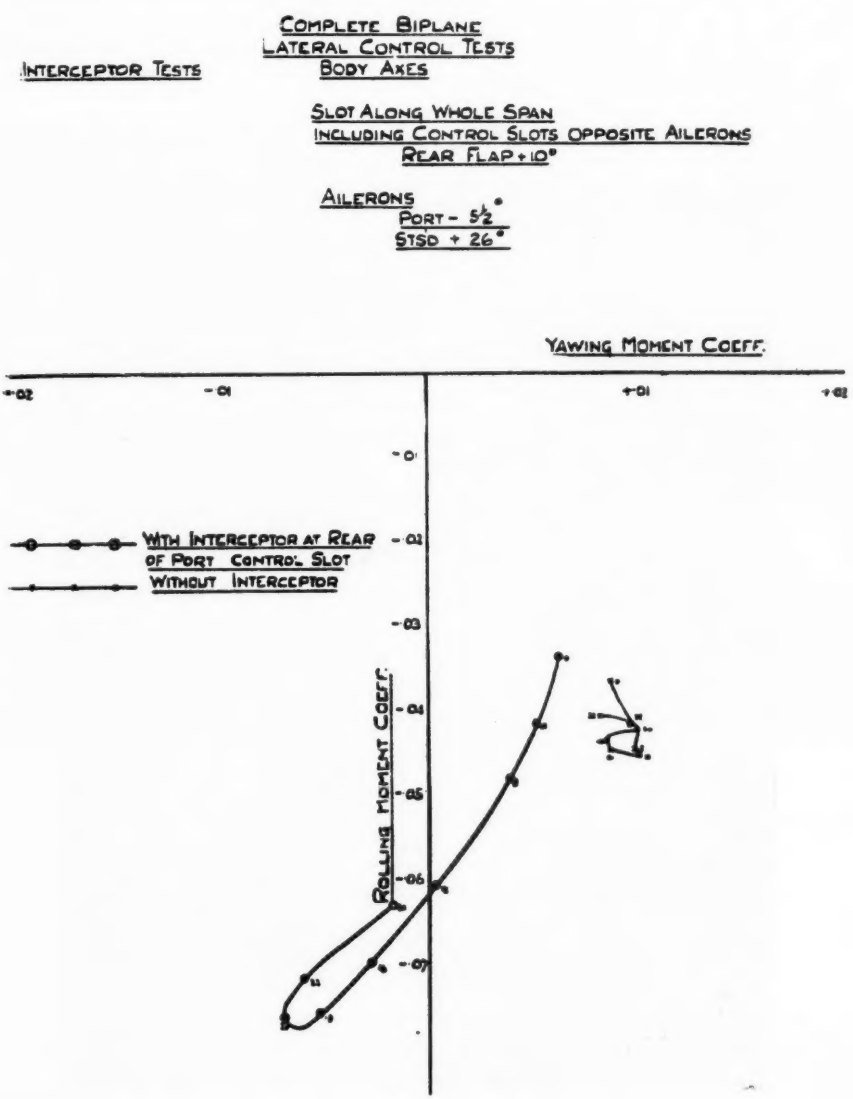


FIG. 60.

obtained in a cheaper manner by varying the wing section, it only shows how little we know about wing sections, and the remark sometimes made may be true, that any one wing section is almost as good as another. Perhaps this may be so when the section is slotted.

In the research work detailed above certain salient features may be summarised :—

1. With thick wing sections an increase in lift coefficient can be obtained by the use of the slot equal in magitude to that with thin wings.

2. As the use of the slot for control purposes is dependent on the lift increase obtained, a similar result in stalled flight can be obtained with both thick and thin sections.

3. Where the aerofoil is used for a portion of the span only the best result

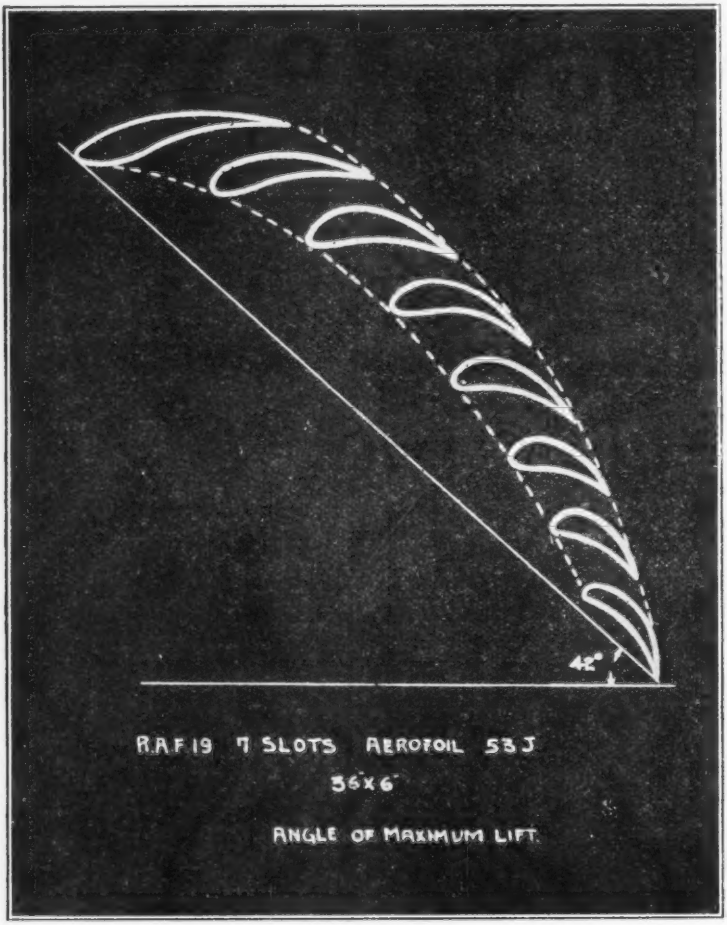


FIG. 61.

for control is obtained when the auxiliary aerofoil is fitted in an intermediate position between the tip and the centre of the wing.

4. With a correctly designed and positioned auxiliary aerofoil, opening and closing automatically, a very good control at and beyond the stall can be obtained without the added complication of control by the forward aerofoil.

5. If increased control is required at and beyond the stall, particularly at very high angles of incidence, the controlled slot or " interceptor " should be used.

In making a survey of the results it must be remembered that these tests show rolling and yawing moments on an aerofoil proceeding on a level keel and do not show righting moments in a roll. It is obvious that it would be impossi-

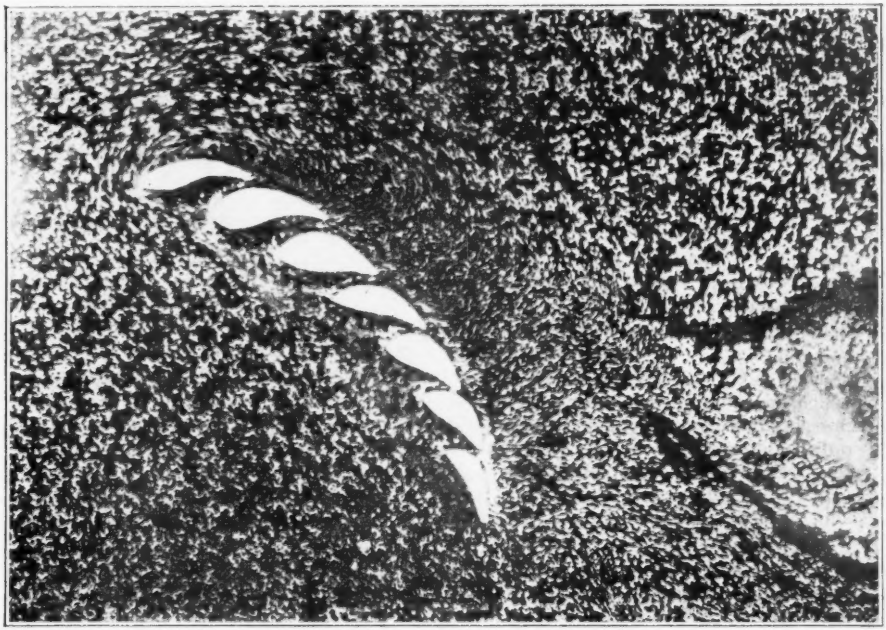


FIG. 62.

ble to use the unslotted control in free flight at the large angles measured without setting up auto-rotation, whereas the damping in roll with the slotted tips permits of the use of the controls in the normal way.

In the perfecting of the slotted wing a wide field is open to those who delight in the exploration of new avenues of scientific research and engineering development. To such the multi-slotted aerofoil (Fig. 61) with its steady air flow up to large angles of incidence (Fig. 62) offers every inducement and every possibility.

The test results which have been given in this lecture have been prepared mainly to aid in the best application of the slotted wing for control purposes, so that with the extension of the angular range in which it is safe to fly and the provision of adequate control throughout, the main source of air accidents and the chief bar to the wider use of flying may be removed.

It is particularly fitting that in this, the 16th Wilbur Wright lecture, we should deal with such problems of control, for in so doing we continue to develop that branch of the flying art of which the foundations were so well and truly laid by the pioneer work of Orville and Wilbur Wright.

I would express my grateful thanks to my assistant, Mr. Russell, under whose direction in my Company's wind channel the results here given, and where not otherwise indicated, were obtained and by whom the arrangements were made for, and the photos taken of, the stream flow around the wing section. I would also once again refer to the many contributions to this subject by Mr. McKinnon Wood, the staff of the R.A.E. and by Mr. Irving and others of the N.P.L.

Mr. H. E. WIMPERIS: Mr. President, Ladies and Gentlemen,—It is a great pleasure to have the opportunity to move this vote of thanks to Mr. Handley Page, but before I do so I want to express to you, sir, the pleasure of the Society in learning that you are willing to accept the nomination of the Council as our President for the forthcoming Session. This next year will be the first complete one of the combined societies, and therefore our President to-night will begin his duties as President of the combined Societies at the end of the summer. He has filled his office in the past with great distinction and has won the respect and, if I may say so, the affection of all those with whom he has come into contact.

Coming now to the motion which I have the honour to move, Mr. Handley Page has given us a very interesting and very able lecture, but it suffers from one grave fault and that is that Mr. Handley Page's modesty has prevented him from saying all the things he might have said about his own share in the work he describes. I should like to remedy this in some measure. He need not fear that I shall drag into the light any misdoings in his past years. I am not St. Peter and this is not the Day of Judgment. Mr. Handley Page many years ago devised his slot. It interested us all immensely. It had some disadvantages which he explored and largely remedied. I don't think anyone then foresaw the present important application of the slot, for owing to the fact that a pilot has only a limited number of arms and legs it is not possible for him to control this slot by hand or foot unless it is linked with some control already existing. Mr. Handley Page has shown how he devised his slot so that it would open and shut without action on the part of the pilot. It is true that it may need in some cases to be interconnected with the ailerons.

Mr. Handley Page has but partly disclosed his share in all this. A platform was built up through a series of years by scientific work carried out at the R.A.E. and N.P.L. When a platform of that kind is provided some people think that the next move is so simple. I do not agree. That scientific platform was open to all of us, but it was Mr. Handley Page who best saw what use could be made of it. I think that the merit of an invention rests with the man who makes the first step forward and not with the one who may improve on it subsequently. I therefore think that immense credit is due to Mr. Handley Page.

I learned to-day from the Chairman of the Aeronautical Research Committee a very interesting fact, and that is it is to Mr. Handley Page that we owe the existence of the duplex wind tunnel at the N.P.L. The large bombing machines which made the lecturer famous during the war were so large that the existing wind tunnels were not long enough and the duplex tunnel had to be built. This wind tunnel has been immensely valuable, particularly for testing such models as those of the Schneider machines which led to such happy results last year.

What is going to be the effect of the invention of the auto-slot? To answer that question involves prophecy, which is dangerous. I shall be cautious. I think that the effect of Mr. Handley Page's invention on those machines proved able to take it will be to reduce the number of crashes by 50 per cent., and the

eliminated crashes will be those of the most dangerous type. That estimate, which I think is a fair one, shows how very important this invention is. It reflects great credit on him as an engineer, and also as a citizen for it is a great triumph for our country. This country lives by its wits. The day of doing relatively simple things is gone. We have got to do clever things. Mr. Handley Page's invention is enormously important for British industry as it means that the enterprise and skill of this country will gain enhanced fame the world over.

I have pleasure in moving the motion:—"That Mr. Handley Page receive the hearty thanks of the Society for his lecture and that he do us the honour of allowing us to print it in our Proceedings."

Lieut.-Colonel J. T. C. MOORE-BRABAZON, in seconding the vote of thanks, said: Mr. Handley Page as a student of aeronautics must realise that this is the high-water mark of his aeronautical achievements—the day that you read your Wilbur Wright Memorial Lecture. Although he has attained success in various walks of life, it is for his lecture that I wish to praise him now.

Apart from the scientific point of view, he has produced something which is going to add to safety. Although in this room we have had many things of scientific value, the thing that is going to appeal to the man in the street is the reduction of the risk of danger. He is a man of a practical nature. He has carried into effect his wonderful invention. As some have said already, this invention is going right round the world to the benefit of this country and, I hope, to himself. I have the greatest pleasure in seconding the motion.

Mr. HANDLEY PAGE: I would like to say how deeply I appreciate the honour of delivering the Wilbur Wright Memorial Lecture, and in that way of being associated with the pioneer work of Wilbur and Orville Wright, who brought aviation out of the realm of vague and hazy ideas conceived by people who had no notion of how to carry them into effect.

When one comes to think of the remarks of the Director of Scientific Research, I might remind you that I read a paper before this Society on the subject of the slot seven years ago. I believe that the slot will lead to economy of performance and to increasing the speed range of the aeroplane.

I beg formally to thank you for the kind way in which you have responded to the vote of thanks, and to Mr. Wimperis and Colonel Moore-Brabazon for the way in which they proposed it.

AIRSCREWS

BY W. E. PARK.

Lecture delivered before the Yeovil Branch of the Society.

It is proposed to confine this paper entirely to the point of view of the propeller constructor.

More than 90 per cent. of the propellers now in use are constructed by shaping from a block formed by the glueing together of hardwood laminations. This type is cheap to produce either individually or in quantity, and has been proved by experience to be satisfactory for all types of aircraft, for tip speeds up to 1,000 feet per second, diameters up to 19 feet and for engines developing over 1,000 b.h.p., without showing any signs of having reached a structural limit.

This construction was standardised for production purposes by the Air Ministry during the War, and the official Handbook of Instructions is a most complete guide to the method of manufacture.

Other forms of construction are, to a certain extent, still in the experimental stage and will be considered chiefly by comparison with the standard type.

Design

The general problem is to construct a propeller to give the best performance, at a definite speed or over a range of speeds, when fitted to a particular combination of engine and machine, and to be strong enough to give efficient service. The solution requires the consideration of:—

1. The variation in engine power and speed under all possible flight conditions.
2. The air flow in the neighbourhood of the propeller, including the effects of adjacent parts upon the streamline flow, the motion given to the air by the propeller, the effect of this upon the resistance and stability of the aeroplane and, at high tip speeds, the effect of the compressibility of the air.
3. The stresses set up in the airscrew, by aerodynamic forces, by centrifugal forces, by torque variation and torsional oscillations from the engine. The deformation of the airscrew under load and its effect upon the aerodynamic loads. The resistance of the material to " fatigue " loading and the " resonance " at any engine speed.

The particulars supplied are always insufficient to permit of an " exact " solution, even if that were possible, and the usual procedure is to design from empirical formulæ, embodying the interpretation of the results of various theories, wind tunnel experiments, and the experience gained from previous designs.

Generally a standard type of blade is specified by its plan form, variation of thickness throughout its length and the typical cross section employed. The diameter and pitch are calculated from empirical formulæ and used to obtain the pitch angles at various sections. From these particulars a drawing of the blade can be made.

The section usually adopted is flat-faced with a maximum thickness at .33 of the chord from the leading edge, this maximum thickness varying throughout the blade; towards the boss the face is made convex to increase the strength. For low speed airscrews (up to 600 feet per second tip speed) it is permissible to hollow out the pitch face to reduce the weight, and for high tip speeds (over 850 ft. per sec.) the leading edge is often modified as shown in Fig. 1.

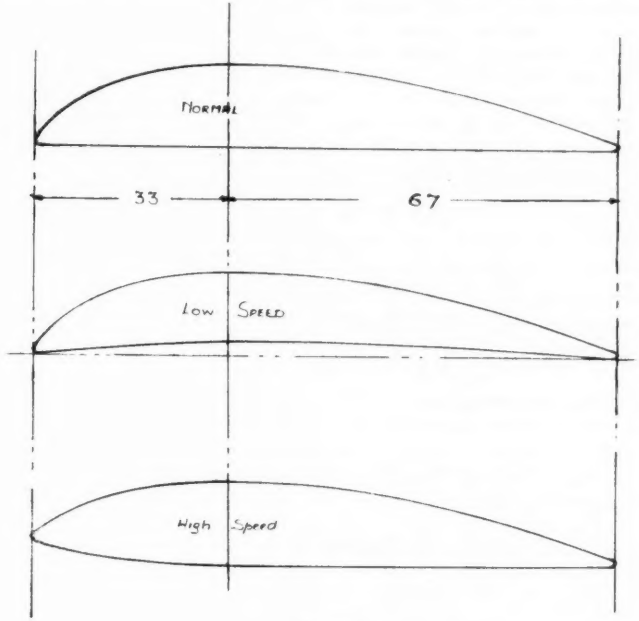


FIG. 1.

An average plan form is given by the figures in Table 1 and these widths are now arranged to give a plan form symmetrical about a line passing through the axis of rotation and the tip of the blade. During the War most designs incorporated a straight trailing edge, although a straight leading edge was used by some designers, but in both of these types the twist under load is greater than with a symmetrical form. The blade with the straight trailing edge tends to twist so as to reduce the pitch, while the blade with the straight leading edge twists in the opposite direction.

TABLE 1.

Section Radius	Plan Form Width	Thickness.
.075	.062	.030
.15	.0714	.024
.225	.079	.018
.300	.083	.012
.375	.076	.0084
.45	.054	.0055
.475	.044	.004

Tip Rad. .02 D.

The values of maximum section thickness given in Table 1 give adequate stiffness and, when used in a propeller with the side elevation symmetrical about a plane of rotation, give sufficient strength to resist the bending forces due to thrust and the centrifugal forces for tip speeds up to 900 feet per second. This symmetrical arrangement generally gives the greatest strength against torsional loads.

The theoretical effect of any increase in thickness is to reduce the efficiency, and in order to use thinner sections the practice of throwing the leading edge forward in side elevation, so that the side elevation is not symmetrical, is adopted by many designers, especially for high speed propellers. The partial balancing of the aero thrust bending forces by the bending due to off-set centrifugal forces, reduces the calculated end grain stresses; but as propellers nearly always fail by cross grain torsional stress, under " fatigue " conditions, it is doubtful if this practice is justified, particularly as such propellers are liable to give trouble with the glued joints and to warp considerably during construction.

The particulars given in a design specification usually include the maximum speed anticipated, the engine and propeller speeds at this condition and the engine b.h.p.

For normal requirements the pitch may be calculated from

$$P = (1.07 \times \text{machine speed in ft. per min.}) / \text{propeller r.p.m. } (N) \text{ feet,}$$

and a suitable diameter is given by

$$D = \{ (\text{b.h.p.} \times 10^{10} \times 90) / N^3 P \}^{\frac{1}{5}} \text{ feet.}$$

The following formula given by Dr. H. C. Watts and often used in the form of a line chart gives approximately the same results.

$$D = \{ (\text{b.h.p.} \times 10^{10}) / (N^2 \times \text{speed in m.p.h.} \times 1.11) \}^{\frac{1}{3}}.$$

Values of the diameter and the tip speed for typical aero engines at 120 m.p.h. are given in Table 2.

TABLE 2.

Engine, h.p.	500	460	700	600	510
,, r.p.m.	1450	1870	954	1380	1100
D in ft.	11.5	9.9	15.5	12.3	13.25
Tip speed, ft. sec. ...	875	970	780	890	765

The diameter may be increased by 2 per cent. for a reduction in speed of 10 m.p.h. and vice-versa. With this type of blade the engine speed decreases as the forward speed of the machine decreases and at climbing speeds the engine r.p.m. is usually .875 of the r.p.m. at the maximum speed.

Where other conditions make it desirable, the diameter may be increased by 5 per cent. or decreased by 10 per cent. by suitable adjustment of the width, thickness and pitch angles throughout the blade, without serious loss of efficeincy.

Drawing

A full size drawing of one blade should be prepared from these particulars, obtained from trial sections. First, the plan form is laid out and faired into the boss. The side elevation may next be drawn, the trailing edge first and the leading edge faired in. The sections are then drawn in on the side elevation to agree with the limits imposed by plan form, side elevation and pitch angles. The lamination lines may now be drawn in, in the side elevation, and it is preferable to have one glued joint passing through the centre of the tip. The side elevation should be faired into the boss to suit the coupling dimensions and the thickness of laminations used. The lamination contours can now be plotted on the plan form and faired in by suitable modifications to the sections. Any

abrupt changes in the lamination lines will mean extra trouble in shaping and will appear as " bumps " in the finished blade.

Lamination patterns may be traced from the finished drawing, and during the preparation of the block the performance of the propeller should be analysed for various flight conditions, using the different aerodynamic theories of the airscrew. At the same time approximate calculations of the end grain stresses should be made.

Any modification shown to be necessary can be made to come out of the prepared block, since a variation of 8 per cent. in blade angles, widths and thickness is usually possible.

Construction

The construction may be divided into three main processes:—

1. The selection of materials and the preparation of the block.
2. Shaping to finished dimensions.
3. Finishing for the protection against atmospheric conditions.

1. *Selection of Materials.*—The timber used will depend upon the type of airscrew, but as a general rule timber should be straight grained, free from knots and local defects, obtainable in large boards with uniform qualities, strong across the fibres and easy to work. Hardness is an advantage.

Soft woods are satisfactory for large low speed propellers. Honduras mahogany is probably most suitable for all normal propellers, while European and American walnut, which is harder and stronger, but not easy to obtain in large planks in quantity, possesses distinct advantages for high speed propellers.

Timbers are tested by bending and should show at least 5,000 lbs./ins.^{2} in compression (mahogany and walnut give about 11,000 lbs. per sq. in.), and an impact test on a notched specimen should produce a long fibrous structure and not a short break. Glueing tests with the glued joint in shear should produce failure by failure of the fibres and not by rupture of the glue film. The way in which the timber fails in these tests is a better index to its properties than the actual breaking loads.

Timber is usually supplied in one inch boards, quarter sawn and naturally seasoned, though further seasoning by kiln or air drying may be necessary. The moisture content should be between 12 and 16 per cent. The timber is generally selected from the history of its growth and felling conditions. After cleaning up the surface this may be inspected for straightness of grain and surface defects, due regard being paid to the position of the particular lamination in the finished airscrew. The value of this inspection depends almost entirely upon the experience of the inspector. The lamination thickness usually lies between 20 mm. and 22.5 mm., except for small propellers, but in the case of high speed airscrews it may be advisable to replace the full length lamination by two thin laminations.

The laminations, after inspection, must be thickened accurately to the specified dimension, and the thickness must be uniform throughout the lamination or difficulty in making sound glued joints will result. They may be marked out directly from the drawing with an allowance of 7 mm. to 15 mm. all round, and cut accurately to shape on a band saw. Each lamination should be balanced before assembly (this balancing is of course useless unless they are cut accurately to pattern), and in selecting laminations for each block, attention must be paid to this balance and to the similarity of elastic properties.

Before glueing, the laminations are scratched by a fine toothed plane iron, generally in the planing machine.

Glueing Up—Choice of Glue

Two main types of glue are used.

(1) *Jelly and Liquid Glues.*—Generally the strongest (up to 1,700 lbs. per sq. inch), these require slight heating up to 150°F. and set fairly quickly, so that the glue-room must be maintained at 70°F. These glues make clean joints that develop their full strength after about 18 hours and are resistant to moist heat. They will keep for long periods.

(2) *Casein Cement.*—Now used very largely. Has a minimum shear strength of 1,000 lbs. per sq. in. and is prepared simply by the addition of water. The mixing with cold water must be very thoroughly performed or lumps will form, making the glue useless. It is fit for use half an hour after mixing, but deteriorates rapidly and should not be used more than four hours after mixing. Can be used at ordinary temperatures, and owing to its slow setting penetrates the fibres of the timber so that the joints are visible, the cement staining the wood a dark purple. The cemented joints develop full strength after six days and are completely unaffected by moist heat, so that this glue is very suitable for tropical conditions.

In glueing up, the laminations are located by a 46 mm. hole through the centre of the boss, this hole being drilled before balancing, and by small blocks glued to the laminations during setting out operations. The glueing table must be robust (three-inch boards are used) and should be fitted with girder members at six-inch intervals. The laminations are painted with glue dropped over the centre spindle, located by the small blocks and the top board placed on top. This also carries girder cross pieces, and bolts hinged to the girders on the table are swung into position and screwed up, starting at the centre spindle and working out towards the tips; a pressure of about 150 lbs. per square inch is advisable. When jelly glues are used the operation must be completed in 10 minutes, but with casein cement the bolts should not be tightened up till at least 20 minutes have elapsed.

The pressure should be maintained for at least 24 hours and the block supported throughout its whole length for a further 48 hours before rough shaping.

Shaping

The block is first bored out to the required size on a high speed boring machine, this bore being used to locate the propeller for all subsequent operations, aluminium packing sleeves being used to accommodate standard spindles. This is followed by " spindling " the block to its finished plan form (with a 3 mm. allowance), a " back pattern " template being used. Rough shaping for individual propellers is carried out by hand, the timber being chopped off with a small hand axe or removed by band sawing to the joint lines. Where more than twenty propellers are required it is economical to use a shaping machine, copying machines of various types being used. French and American practice is to use vertical machines with the tool traversing the length of the blade, two propellers being shaped at once, but with this type it is difficult to make the model propeller sufficiently rigid to ensure an exact copy. In English practice the Wadkin machine and the Sagar machine are used, the timber being removed by bonnet cutters rotating at high speeds (7,000 r.p.m.) moving across the blades and guided by wheels rolling across the " model." The Wadkin uses a hard wood model and shapes one side of the blade at a time, while the Sagar uses a cast iron model which rotates with the propeller to be shaped, so that both sides of the blade are shaped at once. In each case the " model " costs about as much as a finished propeller and about ten minutes per blade is required for a propeller ten feet in diameter. It is not advisable to leave less than 3 mm. above the finished dimensions for each blade after rough shaping.

Finished Shaping

A thick hardwood pattern cut to the finished plan form, with a three-ply strip fixed to the trailing edge side and cut to show the trailing edge drop is used to work in the trailing edge. This being thin gives a definite reference line from which the sections may be developed at various radii, three-ply or steel section templates being used. The section templates are split along the line passing through the centres of the leading and trailing edges and are used with a spirit level, the propeller being clamped to the bench with the boss faces horizontal. The blade is gouged out at each of the radii for which sections are drawn until it is within 1 mm. of the finished contour, and the blade surface between these sections is reduced to produce smooth lamination lines, a plane or spokeshave being used. Before final shaping the trailing edge is checked for "track" and "alignment," relative to the boss face and centre line respectively. The round side of the blade is then shaped in the same way until each section is within 2 mm. of finished width and thickness. The final shaping is carried out with a hard steel scraper 4 in. × $2\frac{1}{2}$ in. × $\frac{1}{16}$ in. with frequent tests of balance and dimensions.

A highly skilled shaper can finish a machined block for a propeller 10 feet in diameter, perfectly balanced and within limits of $\pm\frac{1}{4}$ mm. at any point, in less than ten hours.

A final inspection in the white is usually carried out immediately after shaping, the blades being checked for dimensions and examined for smoothness of contour, surface defects and glued joints; while vertical and horizontal balance are carefully checked. Horizontal balance is usually easily corrected without interfering with the aerodynamic properties, but vertical balance must be carefully watched during the whole process of shaping.

Blades under size may be reclaimed by glueing veneers on to the face where necessary and shaping down. Bolt holes are finally drilled, using a jig (or the engine coupling as a jig) and the propeller fitted to the engine coupling.

Finishing Processes

Propellers may be protected by applying three to five coats of good varnish, the final surface being obtained by hand polishing. This process has been proved satisfactory for most flying conditions (except for seaplanes and extremes of temperature) and effects a distinct saving of time for experimental propellers.

The standard finish is by fabric covering, a linen fabric being glued to the scraped surface of the blade, jelly glue being used, casein cement being unsatisfactory for this purpose. Great care is necessary to get the fabric glued flat on to the pitch face round the trailing edge and over the round face, the final joint being made on the pitch face about one inch from the leading edge. The fabric must be close to the blade everywhere without any air bubbles and the folds at the tip are ironed down on to the pitch face. The fabric is given two coats of size and three coats of varnish.

Seaplane propellers may be protected by a coating of cellulose. Generally six coats are applied, the temperature being maintained at 70°F.; it is found to be more satisfactory if the cellulose is rubbed in by hand rather than sprayed on.

For further protection a brass tip is usually fitted 24 S.W.G. thick, the brass being bedded on to each face fixed with screws, worked round the tips and soldered on the round side, the heads of all screws being soldered in place. During the operation care must be taken not to disturb the balance. Drain holes are provided at the tips for any water that may accumulate under the brass. It is usual to bed the tips on to the fabric, but this is liable to give trouble by cutting the fabric, and in the opinion of the author it would be preferable to apply the tip direct to the timber, letting the brass in to form a smooth surface.

Duralumin tips were fitted in this way to German airship propellers and proved very satisfactory.

Special forms of covering have been tried, including the electro deposition of copper, pigskin tips and lacquering, but for various reasons these have proved unsatisfactory.

The end grain exposed by bolt holes, etc., must be protected by suitable waterproof paint, while the boss part of the blade, not fabricked, is filled and varnished. Final balance can be adjusted by the application of varnish.

General Remarks

An approximate analysis of the cost of manufacture of a typical two-bladed propeller (not including overhead charges) is shown in Table 3.

TABLE 3.

Operation	Percentage Cost. Production Type using Machine	Experimental Propeller
Material	60%	50%
Setting out	4%	6%
Machining	6%	5%
Hand shaping	16%	28%
Fabricking	2%	1½%
Brass tipping	8%	6½%
Finishing	4%	3%

Where spinners are fitted, chiefly to high speed propellers, they should be of three-ply or built up in glued lamination rings from the boss, and substantial ledges for fixing should be provided on the propeller roots. Metal spinners fitted to finished propellers are not satisfactory in service. The wooden spinner generally increases labour costs by about 100 per cent., the three-ply spinner being rather more expensive but more satisfactory in service.

Four-bladed propellers are not generally used except where the diameter is very much restricted; the construction is similar except that the cross laminations are half lapped at the boss, the halvings being staggered relative to each other. As an alternative to four-bladed propellers, with their difficulty of transport, pairs of two-bladed propellers are used at right angles to each other.

Failure nearly always occurs by tip-splitting, or by rupture of the round side at about three-quarter radius; and in the case of blades with excessive drop of the trailing edge by creep of the leading lamination joints. With engines of excessive torque variation and vibration, the failure is usually due to internal heating of the boss and shown first by the fabric stripping off and then by failure of the glued joints.

Special Forms of Wood Construction

To reduce tip-splitting, propellers have been built up of multi-ply boards (about twenty plies $\frac{1}{16}$ in. thick) forked together at the boss and built up by glued on laminations of hardwood. In addition the French have experimented with a construction, using knife-cut veneers 2 mm. thick, arranged with the grains crossing and pressed roughly to shape during glueing together.

Experiments carried out during the timber shortage of the war showed that laminations could be made up of any number of pieces glued together and used to produce a satisfactory propeller (one propeller made up of boards less than one foot square was tested under overload without failure), but generally, owing to the variation of elastic properties, joints in laminations are not used. In

view of the fear of a timber shortage, however, it should be possible by a suitable grading of timber to use mixed construction, hard woods for the highly stressed parts and soft woods for building up the contours.

Metal Construction

Although hard wood propellers have proved equal to all the demands made upon them, the possibility of difficulties of supply of material, all of which is imported, has prompted the investigation of production in metal construction. The construction of metal propellers would be a comparatively simple matter

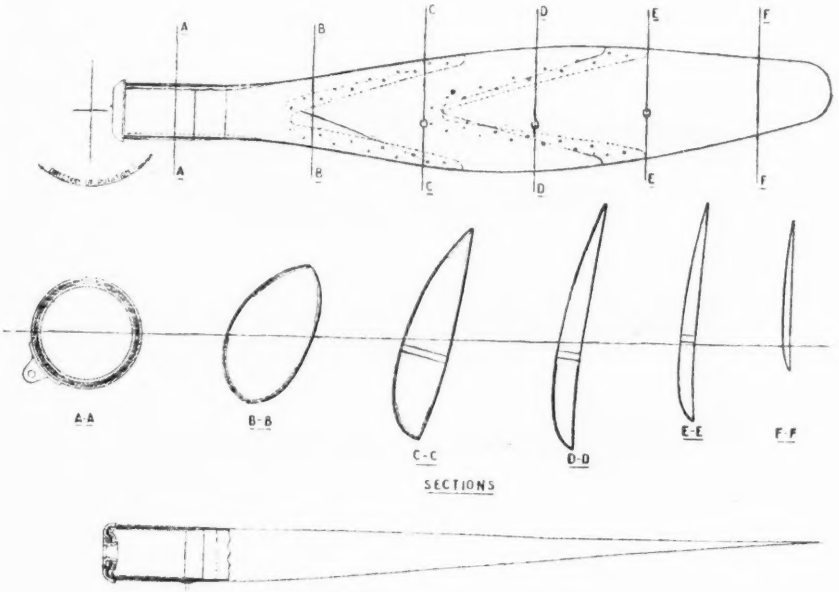


FIG. 2.

General arrangement and sections of a Leitner-Watts Metal Airscrew Blade.

if only static loads were to be considered, but the stresses set up by excessive torque vibrations of the average aero engine renders the problem a difficult one. The air damping on the propeller blades is not sufficient in itself to reduce this vibration, and any material used should possess the property of vibration damping against resonance under varying loads. This generally requires a material with a high natural elastic limit, a low value of the limit of proportionality and a low value of the modulus of elasticity or rigidity. Timber satisfies these conditions, steel generally does not, particularly mild steel, and steel propellers under severe test conditions have generally failed by "fatigue." The light alloys of aluminium and magnesium satisfy these conditions to a much greater extent and consequently should prove suitable for propeller construction. In every case the material must be stressed nearly to the natural (or fatigue) elastic limit to secure the full advantage of the elastic properties of the material. Where propellers have failed near the boss (by internal heating) under circumstances indicating torsional vibration, stiffening up the boss has not proved a remedy;

it has either moved the point of failure to the propeller tips or to the engine crankshaft.

The Leitner Watts Propeller

The only steel propellers in use in this country are those made by the Metal Propeller Co., of Croydon. First manufactured in 1917, the construction consists of the welding together of plates pressed to the required shape, suitably stiffened and fixed to a special hub. Mild steel is used, 20 S.W.G. thick, the outer plates and the stiffening laminations being cut to shape and edge welded and spot welded together. After each welding operation the plates are annealed. The plates are then pressed to shape while hot in a hydraulic press, corrugations being formed in the pitch face to increase the stiffness. The halves are then edge-welded together, the ends being left open for the insertion of stiffening

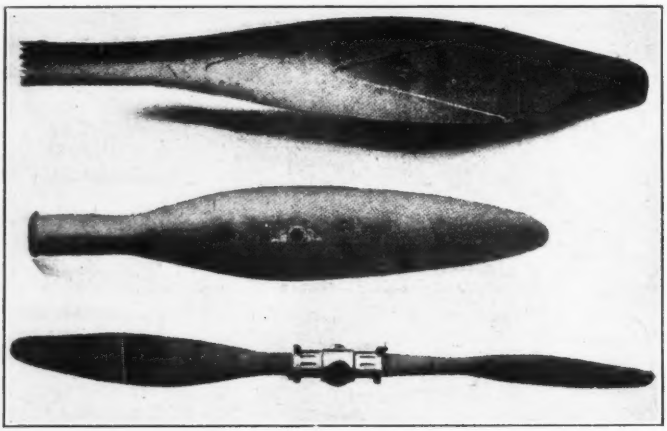


FIG. 3.

pieces. The root is then built up, an inner sleeve being inserted and the serrated edges of the root closed over this sleeve. An outer sleeve with a collar formed on it is forced over the end and secured by a screwed plug to the inner sleeve and by rivets through both sleeves and the blade root, the whole being then soldered or welded together. The root is then machined to fit the hub. Figs. 2 and 3 show the construction of the blades.

The blades are then trued up by hand, stiffening pieces being inserted and the tips welded up; drain holes are provided at the tips and roots. Balance is adjusted by the insertion of a tube carrying a small balance weight (welded in place after test) in the screwed plug at the root. The blades are sand-blasted and enamelled.

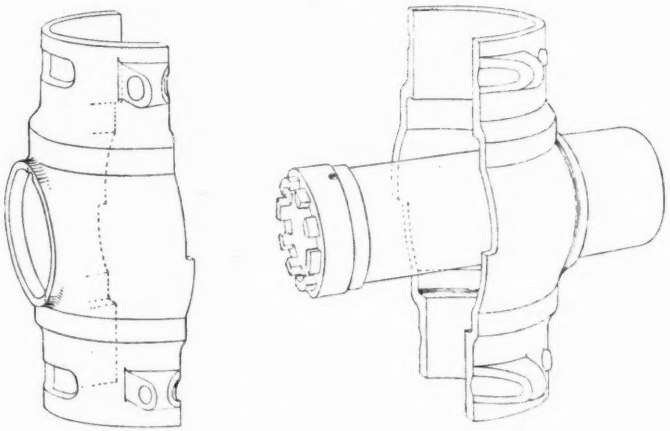
The hub fixing (Fig. 4) is a feature of the design, affording the possibility of the use of two, three or four blades with an adjustment of pitch, so that comparatively few standard blades will cover many types of machine. The hub consists of machined steel forgings, the back half fitting on the tapered engine shaft and being secured with a nut. The halves clamp the propeller blades in place, the joint faces butting on one side and locating the hub. The pitch is adjustable by slacking off the clamping bolts and screwing up the bolt 12, shown in Fig. 5. A vernier scale is provided and after adjustment to the

required extent the blades are locked by the wing nut and then clamped up in place.

These propellers are somewhat heavier than corresponding wooden propellers, especially in small diameters, but it is estimated that for diameters over 16 feet the Leitner Watts propeller can be made lighter than the normal type of wooden propeller. At the present time they are considerably more expensive to manufacture in small quantities.

HUB SOCKETS.

The blades fit into a steel hub made up in halves, and which are made in three types for 2, 3 or 4-blade propellers. These are made from steel forgings, and the construction of these sockets can best be gathered from the diagrams below.



Construction of Hub Socket—New Short Type.

FIG. 4.

Light Alloy Construction

This was first used by Reed, in America, and taken up by the Curtiss Co. of America, and more recently by the Fairey Aviation Company in England. The use of a material relatively strong in shear (as compared with timber) and possessing suitable elastic properties permits the employment of thinner tip sections, which should give higher efficiency, particularly at high tip speeds. With the original Reed construction the propeller is made of a single duralumin plank (up to $1\frac{1}{2}$ in. thick) milled to shape, and then bent and twisted in a special machine to give the required pitch angles throughout the blade. The blade is then heat treated in a salt bath and polished to its final dimensions. Bosses, of cast aluminium or hard wood, are built up to suit the engine coupling and the airscrew finished for balance and protective covering. Fig. 6 shows a typical Fairey-Reed propeller. These propellers are two to three times as heavy as a corresponding wooden propeller (depending upon the tip speed) and very much more expensive to manufacture in small quantities. When tested to destruction they usually fail by the blades twisting flat.

A development of this construction is the use of a solid forging of duralumin or magnesium alloy machined and polished to shape.

The Short Metal Airscrew

Shown in Fig. 7 is a development of the thin-sectioned duralumin blade offering the possibility of four-bladed construction, lower first cost and ease of transport. The blades are separate and notched at the ends so that they fork together at right angles, being secured by Vee blocks and bolts. This construc-

Diagram of Blade Pitch Adjusting Gear.

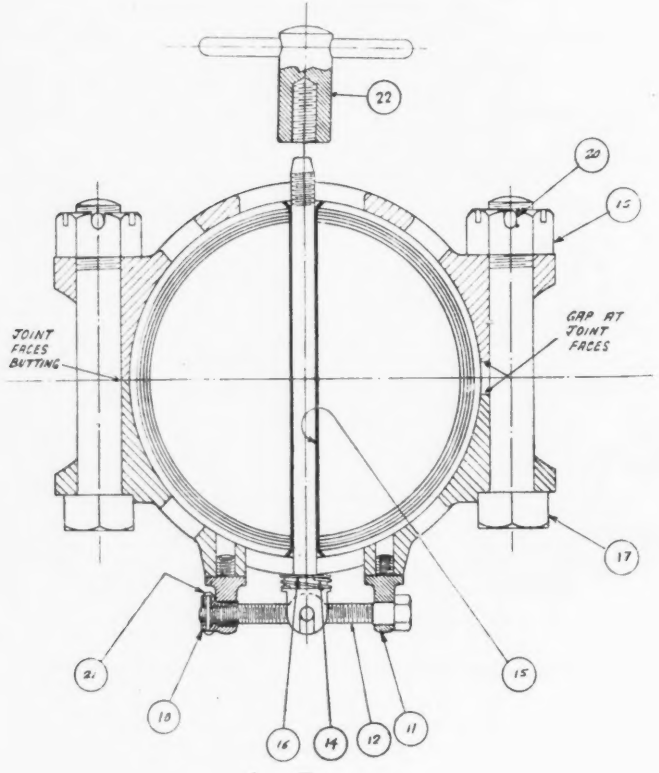


FIG. 5.

tion avoids excessive twist of the blades at the roots, with the falling off in efficiency at climbing speeds usually associated with this type of airscrew, and the boss construction is sufficiently rigid to avoid vibration.

A Leitner Watts propeller of the light alloy type is also made, the blades being profiled from duralumin forgings and fixed in the standard hubs. Many other forms of metal construction are still in the experimental stages of development.

In conclusion, the author would thank Dr. H. C. Watts, of Metal Propellers, Ltd.; the Fairey Aviation Co.; Short Bros.; the Held Glue Co.; and the Lactocol Sales Company for their assistance and for information used in this paper.

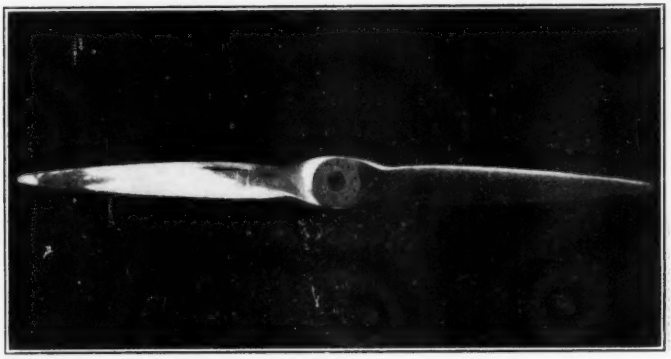


FIG. 6.

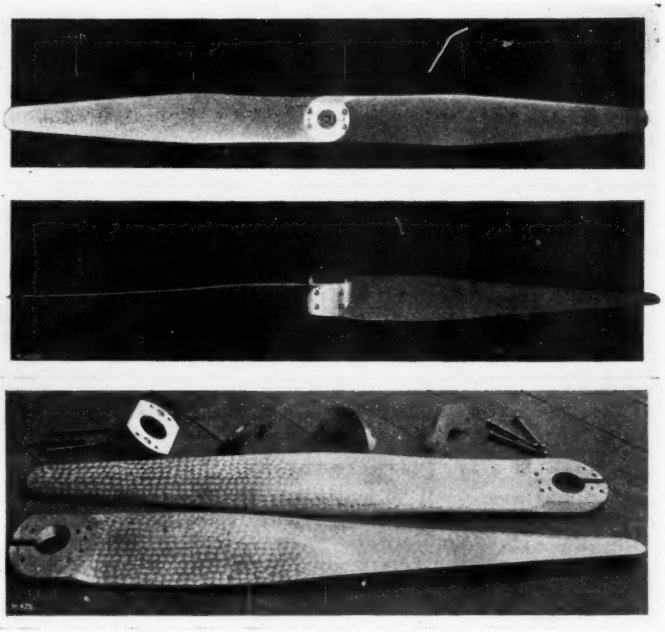


FIG. 7.

DISCUSSION

Mr. DAVENPORT, referring to conversion of machines to seaplanes, asked if No. 12 tipping was satisfactory?

Answer.—Yes, for flying over sea. Generally the failure is due to the fabric ripping at the edge of the brass. Suggest scrapping fabric on all seaplane propellers. In the first Atlantic flight attempts the propellers on the Sopwith machine were unfabricked and gave good service in the test flights, one of

these being used on the " Wallaby " Australia flight later, whereas the Vimy propellers, which were fabricked, gave trouble owing to the fabric stripping during the flight.

Captain KEEP: Screws in the metal tips have often been found to break, and an Air Ministry Memoranda suggests that an alternate tip fixing might be devised; was there any objection to a hollow copper rivet going right through the blade?

Answer.—In the past, where rivets right through the blade have been used, the metal sheathing extended round the trailing edge and the tendency was to split the trailing edge. Hollow rivets passing through the blade might seriously affect the efficiency. During the war the Germans used a thick duralumin tip sunk into the leading edge and fixed by screws, beaded in and duralumin rivets.

Mr. METTAM: Is a pusher propeller less efficient than a tractor?

Answer.—With the pusher the air entry to the propeller is moving faster than the relative speed of the machine and this should cause a lower efficiency. As the resistance in the slipstream is generally reduced the same performance can be obtained by using a well designed pusher propeller. An approximate correction is to add $1\frac{1}{2}°$ to the pitch angles of a corresponding tractor design, this assuming an increased air entry speed of about 6 per cent.

Mr. GIBSON: Is there a reasonable efficiency in the " Wal " tandem?

Answer.—The rear propeller working in the slipstream of the front propeller gives a much lower efficiency (about 85 per cent. of efficiency of front propeller), but generally with this arrangement the two engines are only used for " getting off " and level flying is carried out on the front engine only.

Mr. DAVENPORT asked if new engines should have calibrated wind brakes supplied as the aeroplane maker could not tell if his machine was getting the full power.

Answer.—It is very difficult for the aeroplane designer to tell if the engine, propeller, or machine is wrong with a new type test. The airscrew designer cannot guarantee a propeller for an engine test as two propellers made to the same drawing may vary in engine power absorbed from 570 h.p. to 650 h.p. The test propeller should be calibrated before fitting to the engine, or the engine tested on a standard propeller before flight tests. The power absorbed by a propeller depends upon the effect of adjacent objects on the air flow.

Captain HILL: Is a thick blade section efficient?

Answer.—Experience tends to show that thick tip sections are not so inefficient as generally supposed, and blades have been thickened considerably (to increase stiffness) without any adverse effect on the performance. Thick root sections are inefficient as they affect the air flow over the fuselage. This effect is more noticeable in the case of an engine (such as the Napier " Lion ") which gives a good fuselage entry than in the case of an engine (such as the Bristol " Jupiter ") which shields the root portion of the propeller.

Mr. METTAM: Could timber airscrews be used for high speed work?

Answer.—Yes. Timber airscrews have been used for tip speeds of over 1,000 ft./sec. A timber airscrew was used for the trial flights of one of this year's Schneider Cup machines with very good results, while a timber propeller in the " Tiger Moth " gave 200 m.p.h. with a 130 h.p. engine. Generally while a metal propeller has some advantages for high speed work owing to the thinner sections and better root form possible, a timber propeller gives a better climb.

Mr. DAVENPORT: Does the fitting of a " spinner " increase the speed of a machine?

Answer.—If the spinner is designed to improve the " lines " of the machine there is an increase of speed of 1 to 2 per cent. If the spinner is not designed to fit the machine it may reduce the speed obtained.

Mr. PENROSE: If the rivets mentioned by Captain Keep caused a drop in efficiency, would not the large bolt heads and stiffening corrugations in the Leitner-Watts airscrew also materially reduce the efficiency?

Answer.—These projections would probably cause a drop in efficiency, and in the modern Leitner-Watts airscrew a different type of internal stiffener is used eliminating the bolt heads. Hollow rivets would be more inefficient because they would allow a flow of air from the pitch face to the round face of the blade.

Mr. GIBSON asked for information as to the relative advantages of mahogany and walnut for propellers.

Answer.—Walnut is harder than mahogany and generally makes a stronger propeller. More care is necessary in making the glued joints as the glue does not sink into walnut so readily. With cold water glue the joints should be tightened up slowly, at least twenty minutes being taken for this operation. Walnut is very difficult to obtain in selected boards and could only be used for experimental propellers.

Captain HILL asked if the vortex theory or the combined momentum and blade element theory gave more accurate results in practice than the simple blade element theory.

Answer.—The lecturer found that the simple blade element theory without corrections for inflow velocity and infinite aspect ratio gave surprisingly accurate values for horse-power absorbed. Dr. Watts in " The Screw Propeller in Air " gives comparative results for many propellers calculated both with the simple blade element theory and including the effect of inflow velocity. In nearly every case the results obtained agreed more closely with the simple blade element theory.

In connection with the comparison of the accuracy of the various theories it was interesting to note that similar machines built to the same performance specifications and with similar engines gave very different results when fitted with the same airscrew.

Captain HILL: Could the lecturer give some information on loss of efficiency at high speeds?

Answer.—Not much is known on the question. Model and full-scale experimental results do not agree, the effect being much less with full size propellers than with wind tunnel experiments. In the case of one machine fitted with a " Jupiter " engine, the difference in horse-power developed at 1,750 r.p.m. and 1,870 r.p.m. just balanced the loss in efficiency due to increase in tip speed with various types of propeller. At high tip speeds it is possible that a different type of section with a less rounded leading edge would be more efficient. Tests at low speeds have possibly no relation to the results obtained at tip speeds over 950 ft./sec.

Mr. B. C. JONES: Can the Air Ministry Handbook on Airscrews be obtained by the public?

Answer.—Yes; and it is the basis of all methods of timber construction.

Mr. COLSON asked for information on the American Steel Propeller Co.'s product and why three blades were used?

Answer.—This propeller is similar to the Leitner-Watts, though not a copy of it. The object of the design is to use as few types of blade as possible and to fit different engines and machines by using two, three or four blades. Theoretically two blades are better than three and three better than four.

Mr. PENROSE asked if pusher propellers were still efficient if the diameter of the body in front was greater than that of the airscrew.

Answer.—Yes; if the machine is arranged to give a reasonably free air flow to the propeller and the propeller is designed to suit the actual conditions.

In a flying boat designed in 1919 the small diameter pusher propeller could not be seen from the front of the machine, but a good flight performance was obtained, although the horse-power absorbed by the propeller on the machine was very different to that absorbed when tested on the spinning tower.

THE ALIGNMENT AND INSPECTION OF COMPONENTS

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LICENSED GROUND ENGINEER, CATEGORIES A, B AND C.

Paper read before the Yeovil Branch.

This paper should be regarded as a continuation of the one I read before you last session and is intended, primarily, to cater for those who wish to sit for a Ground Engineer's Licence.

My previous paper dealt with the alignment and checking of fuselages. I propose in this paper to deal with the alignment of certain other components, and also with the inspection of components.

We will take first the case of main planes.

The Alignment of Main Planes

1. The same principle applies to main planes as to other structures and components, they should be checked in three planes or views:—

Plan view,
Front view and
Side view (or end view).

2. *In Plan.*—The check should be for profile, the spars for straightness and the general arrangement of the structure of the plane against the drawing.

3. *In Front or Edge View.*—The check should be for straightness (or non-bowing) of spars and consequently of the plane.

4. *In End View.*—The plane should be checked for " winding " (this particularly applies to planes of deep section, as used on monoplanes) and the profile of the rib should be examined to ascertain that it has not become distorted in the assembly.

Type A—Parallel Spars (Fig. 1)

The check in the various views is as follows:—

1. *Plan View.*—The plane should be supported on trestles with blocks under the spars.

The following points should now be checked:—

2. Over-all length at each spar and the chord (or width).

3. *The spar centres,* either by measurement or by means of a jig, at the root end and the outer compression rib.

4. The spacing of the compression ribs.

5. The separate bays should be cross trammelled for squareness, commencing at the root end.

6. The position of the bolt holes at the various joints by means of jigs or by measurement.

7. A line should be run along the centre of each spar, from the root to the outer compression rib, for the purpose of checking that the spar is straight. In addition, the leading edge should be checked for straightness.

8. The compression ribs for straightness.

9. The spacing and number of light ribs, and the ribs for being straight and not twisted.

10. The wing tip should be to plan.

11. The position and alignment of aileron hinges, by means of a jig.

12. The root end rib for squareness with the spars or as called for on the drawing.

13. The plan of the plane generally should be checked against the drawing.

14. *In Front or Edge View.*—For checking in this view the plane should be hung on arms projecting from pedestals, the arms being placed under the spars and adjacent to the compression struts.

15. The straightness of the spars and leading and trailing edges may then be tested by means of a line.

16. *End View.*—While supported on the arms, the checks in end view may be made. The plane should be tested for "winding," by sighting, but if of rigid construction the plane should be placed on trestles and "winding strips" used.

17. The profile of the end rib should be checked against the template. In the case of planes, the ribs of which are not made in jigs, suitable templates should be made for checking the profile of the ribs of the finished plane.

Type B—Spars Evenly Converging Each Side of Centre-Line (Fig. 2)

1. In this case, after the spar centres have been checked at the root end and outer compression strut, the centres of the compression ribs will be carefully checked off and the bays cross trammelled.

2. Each diagonal should be of equal length. The root end rib will be the datum from which the measurement for the compression ribs or struts is taken.

3. Each spar will then be tested for straightness by means of a line along the centre.

4. The remainder of the alignment check will be substantially as in the previous case.

Type C—Back Spar Raked Forward (Fig. 3)

1. In this case, after the spar centres have been checked at the root end and outer compression strut, the front spar should be checked for straightness by means of a line.

2. The front spar can now be used as the datum.

3. The root end rib should be checked for being at right angles to the spar.

4. This may be done by a large square, or if no square is available, by marking off on the end rib a length equal to that of the first compression rib and cross trammelling the four points thus obtained.

5. The squaring of the end rib should be effected by adjusting the cross-bracing wires in the first bay, *all the other wires being slackened off.*

6. After the rib has been set at right angles to the front spar and the front spar being straight, the remainder of the plane should fall correctly. If it does not, there is an error in the construction.

7. The compression ribs should be checked for spacing and for being at right angles to the front spar by means of a large square.

8. Cross trammelling is not done in this case.

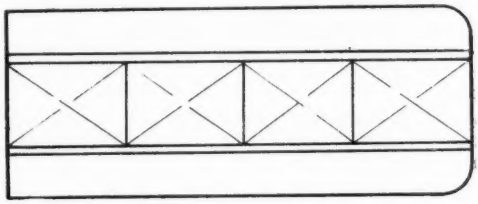
9. The rear spar should be tested for straightness by means of a line.

10. The remainder of the alignment check will be substantially as in Type A.

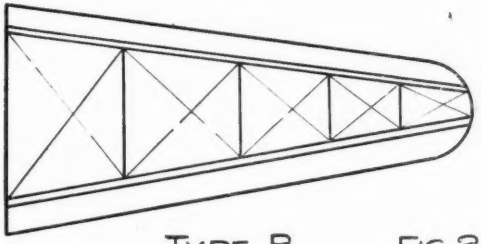
Type D—Both Spars Raked Back and Converging (Fig. 4)

Dimensions given being spar centres and rake of front spar.

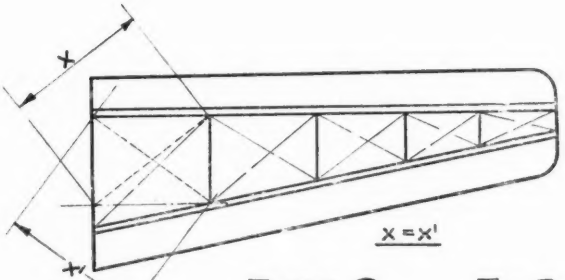
1. The best way to check the alignment of this type of plane is on the jig



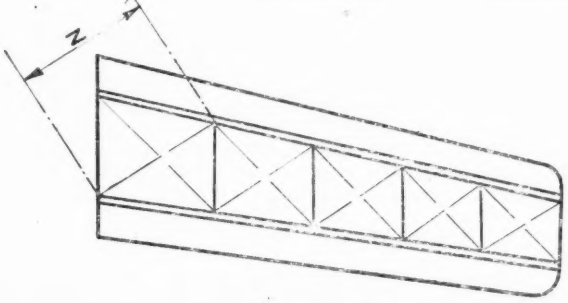
TYPE A FIG. 1



TYPE B FIG. 2



TYPE C FIG. 3



TYPE D FIG. 4

board on which it has been constructed. If, however, this is not available the following procedure may be adopted:—

2. Check spar centres at root end and outer compression rib.

3. Check front spar for straightness by means of a line.

4. The front spar will then be used as the datum.

5. If only the dimensions stated previously are given, the plane should be set out to half or quarter scale and the dimension " Z " obtained; this can then be multiplied by two or four, as the case may be, and applied to the job.

6. The end rib should then be set to this dimension, which will bring the rear spar into position.

7. If, however, the drawing office is available it might be asked for a definite dimension " Z."

8. Adjust all cross-bracing wires, so that the front spar lies straight, the remainder of the plane should then fall correct, if it does not, there is an error in the construction.

9. Check compression ribs for spacing and for being parallel to end rib.

10. Cross trammelling is not done in this case.

11. Test the rear spar for straightness by means of a line.

12. The remainder of the alignment check will be substantially as in Type A.

Alignment of Tail Planes, Fins and Controlling Surfaces

1. Checking the alignment of these components follows closely the procedure for the main planes.

2. Usually the components will be assembled in a " flat " jig or on a laying-out table, which has been previously checked for profile and over-all dimensions. In this case the component is tried in the jig to ensure that the component has been accurately made. If the component is not jig-built, it should be checked directly against the drawing.

3. If the component is cross-braced it should be cross trammelled in the usual way to check the " squareness " of the bays, commencing with the centre bay.

4. The position of all attachment fittings should be carefully checked by means of a jig or by measurement.

5. The position of all hinges must be accurately checked. If no jig is available it is advisable to try the component against an approved component with which it mates.

6. Operating levers should be checked for position, secure attachment and for angular " setting," although usually the latter is fixed.

7. The greatest trouble experienced with these components is that of " winding " and they should be carefully " sighted " to ensure that this defect is not present to any extent. The best means of testing this, in the case of long narrow components such as ailerons, is to fix the component on a set of dummy hinges and sight the trailing edge against a cord which has previously been strung out parallel to the centre line of the hinges. Any " winding " of the component will be then immediately apparent.

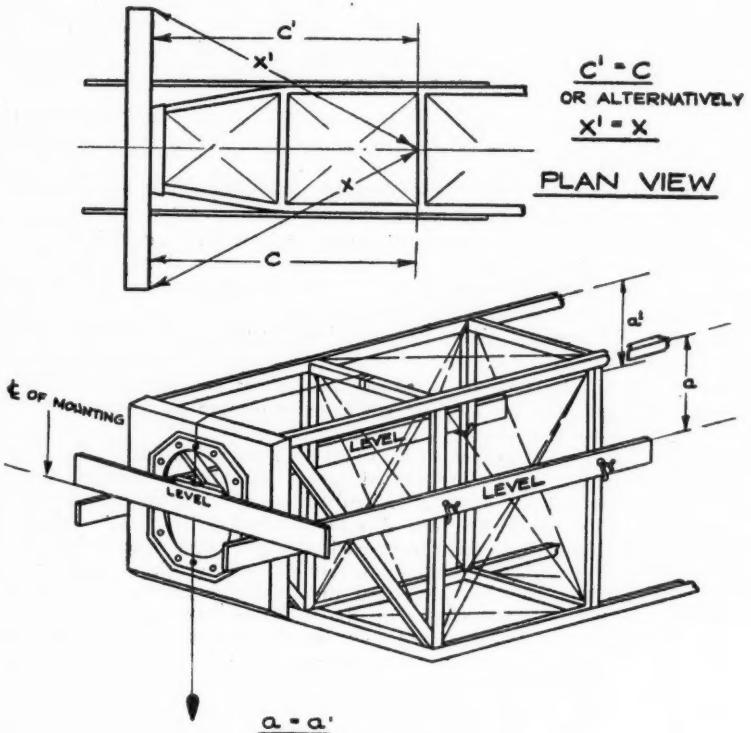
8. A small degree of " wind " can sometimes be taken out during doping, by a skilled operator, but it is usually preferably to have this rectified before doping as, unless very great care is taken, it will increase on doping.

Alignment of Engine Mountings

1. These can be divided into two main classes:—

I. Plate type for radial engines, Fig. 5.

II. Horizontal bearer type for cylinder-in-line engines (including " V " engines), Fig. 6.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X'
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C' = C
OR ALTERNATIVELY
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FIG. 5.

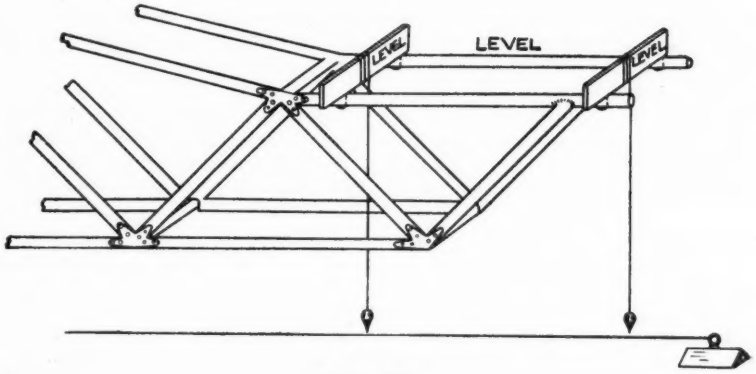
LEVEL
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FIG. 6.

2. The fundamental requirement for the correct alignment of an engine mounting is that the engine thrust shall be exerted in a direction parallel to the fuselage datum line in both plan and side view or in any other specified direction.

In practice this is ensured by lining up the mounting in the required manner before the engine is fitted.

3. We will take, first, the plate type mounting for the radial engine, and in order to simplify matters will assume that the engine thrust is to be exerted in a direction parallel to the normal line of flight.

When an inspection jig is not available, the following check measurements should be taken on the plate, after fixing in position (Fig. 5):—

(*a*) Centre of plate to fuselage datum (vertically and laterally).
(*b*) Face of plate for being vertical by means of a plumb line.
(*c*) Face of plate for being " square " to fuselage datum line in plan view.
(*d*) Plate not rotated about its axis, *i.e.*, locating bolt hole in correct position.

4. In the case of the type of mounting in general use for cylinder-in-line engines, the same principles apply, and when an inspection jig is not available the method of lining-up the mounting is as follows:—

(*a*) The fuselage is first levelled up and then a ground line is rigged up.
(*b*) Two straight edges are placed across the engine bearers, one at the front and one at the rear, and the bearers are checked for being " level " transversely and also for " winding."
(*c*) A plumb line is dropped from each straight edge exactly central to the bearers; these plumb lines should both cut the datum line or ground line, thus showing that the engine mounting, as a whole, is parallel to and central with the fuselage datum line.
(*d*) The bearers should be tested for " level " in a fore and aft direction.
(*e*) The height of the top of the bearers, in relation to the fuselage datum, should be checked.
(*f*) The centres of the engine fixing bolts or engine feet positions should be accurately measured and cross trammelled—although it is preferable that a jig should be used for this check.

Inspection of Covered-Type Components

1. After the components have been checked for alignment it is necessary to thoroughly look over them to ascertain that all the requirements of the drawing, specifications and standard aircraft practice have been complied with.

New Components

2. All materials, fittings, tubes and other parts, together with the various treatments and processes employed in their manufacture, must be in accordance with approved drawings and appropriate specifications, and all details before assembly must bear the necessary part numbers and inspection stamps.

Construction

3. All timber struts must bed down in their sockets. This can be ascertained by marking the bottom of the socket with, say, red paint, and pushing the strut home and then removing it. If the strut has properly bedded down the bottom will be evenly covered with the paint. This point is important, as if the struts do not bed in the sockets the compression loads are frequently taken by the sides of the sockets, which are not designed to take these loads. In addition, after the aircraft has been in service a little time the struts will have become further embedded and the rigging of the aircraft will be affected in consequence.

4. Metal struts must bed in their sockets, or must be an even fit on the pins or rivets which take the compression loads.

5. Fork-ends at the end of metal struts must not be strained sideways, but must line up correctly with the lug on to which they are pinned.

6. In the case of metal struts taking both tension and compression loads, the bolts, pins or rivets fixing the ends of these struts must be an accurate fit in both the struts and the attachment fittings in order that play shall not develop in the joint.

7. Tie-rods and streamline wires should be tried for tautness. It is not desirable that these should be too taut, nor is it desirable that they should be "soggy." A happy medium should be aimed at. I would point out, in this connection, that it is easily possible to put a greater load on the surrounding structure by the over tightening of a tie-rod, than the structure is called upon to withstand under normal flying conditions. Bowed struts, bent fittings and, in fact, distorted components, are some of the evils arising from over taut tie-rods. The tie-rods should be sufficiently taut to hold the structure in proper rig.

8. After the right degree of tension has been obtained, and the component rigged true, an individual inspection of each fork-end on the tie-rods and streamline wires should be made to ascertain that the correct length of thread is engaged with the fork-end. An inspection hole is provided in each fork-end for this purpose, and a piece of hard wire or other suitable instrument is inserted in this inspection hole to ascertain that the tie-rod is engaged as far as the hole.

9. Rivet heads should be accurately formed, properly closed down on the parts riveted together, and must be of the correct size and not split. Any rivets, the heads of which do not comply with these requirements, should be replaced.

10. Bolt heads and nuts should seat evenly, as otherwise not only is a bending load put on the bolt, but undue stress is caused in one section of the thread; also the clamping effect on the fitting is reduced.

11. Bolts and nuts used in conjunction with softer material than that from which they themselves are made should always have a plain flat washer under the head and under the nut, in order to prevent local damage to the parts being bolted together.

12. The specification for aircraft bolts calls for a small radius under the head of the bolt; the edges of all bolt holes should therefore be radiused to correspond, in order to prevent the cutting action on the bolt and also to permit of the bolt head seating properly.

13. In the case of hollow metal members which are required to have liners or packing fitted at certain joints or bolt holes, a special check must be made that these strengthening pieces are fitted. If necessary, small inspection holes should be drilled in the outer member for this purpose.

14. All parts, both timber and metal, must be adequately protected against atmospheric effects before being assembled with any other part.

All woodwork should be varnished or painted. All metal parts should be painted, enamelled, zinc coated, anodically treated or otherwise suitably protected against corrosion. Bolts, rivets, etc., passing through both woodwork and metal work must be protected before being inserted in the hole.

15. Pulleys should revolve freely on their bearings and must not bind on any portion of their mounting. The appropriate cable should be tried with its correct lead in, to ensure that it has a fair lead in. It should not ride on the edge of the pulley, on another cable, nor unduly foul the cable guide. In all cases where the cable guide is definitely used to bring the cable into correct alignment with the pulley, the guide should be lined with fibre, copper, brass, aluminium, or other suitable bearing material.

16. The safety guides, which do not normally come into contact with the cable, but are used to prevent the cable jumping the pulley, should be inspected

to see that they clear both the cable and the pulley, but that they do satisfactorily fulfil their purpose of preventing the cable jumping the pulley.

17. " Setting " and filing of metal parts is not permitted during assembling. Parts which are found to require adjustment on assembly should be sent back to the department in which they were manufactured for the necessary adjustment and re-inspection. If all parts have been correctly made to drawing, they should assemble without " setting " or filing being required; when this is required, however, it is usually an indication of error in manufacture or design, and steps should be taken to remedy same.

18. Metal or wood parts which are bruised or damaged are not acceptable in the assembled component. Steps must be taken to rectify the damage either by entirely replacing the part or with the concurrence of the inspector by effecting a suitable repair.

19. Examination should be made of minor components to ascertain that no cracks have been started during the assembling operations.

20. The Inspector must ensure that all ribs are properly butted and that wiring plates and other fittings are adequately bedded down, excessive pulling of fittings into timber being avoided. Wiring lugs must be in precise alignment with the bracing.

21. Excessive and/or unequal initial tensions of bracings should be avoided and all wires should be correct as to size, length and lengths or engagement and adjustment. In the case of internal bracings the inspector must ensure adequate clearance to prevent chafing of the bracing wires with the structure under all conditions of flight.

22. NOTE.—Precaution shall be taken to ensure that each cable complete with end fittings is stretched by means of a load equal to half its nominal strength before being fitted.

23. The practice of drilling timber members directly through metal parts must be rigorously discouraged and steps taken to ensure, as far as possible, the drilling of all parts before assembly. If drilling in position is unavoidable, subsequent dissembly of the parts should be insisted upon in order to verify whether correctness and alignment of drilling has been achieved. If, in an extreme case, dissembly cannot be carried out, the inspector must make a special inspection of each hole before the bolt is inserted.

24. The practice of plugging incorrectly drilled holes in important members is prohibited and, in minor members or unimportant positions, must be specially sanctioned by the inspector.

25. Owing to their liability to cause failure, deeply-cut gauge lines, for the positioning of fittings, are forbidden; on wood members only pencil lines may be permitted.

26. Packing blocks in the spindled portions of spars must be of the same timber as the spars and must be fitted so that the grain and direction of the annual rings match those of the spars as nearly as possible, in order that unequal shrinkage of the spar and packing block and consequent liability of the spar to subsequent splitting may be avoided.

Final for Covering

27. When all the points in the foregoing have been correctly checked, the component will require a final inspection before covering. This inspection consists of a general examination of the component to ascertain that no incidental damage has occurred since the previous inspection was made, and also that all nuts on bolts or studs are suitably locked by means of spring washers, castle nuts and split pins, or by being riveted over. Generally speaking, damaging the threads by means of a centre punch is not considered to be sufficiently positive for aircraft work. Swaged rods and streamline wires should be locked in the fork-ends by means of the lock nuts provided, and in fact the whole structure

must be locked up so that nothing can possibly come loose while the aircraft is in service.

28. If wireless is to be fitted to the aircraft, the earthing and bonding should have been carried out, and the resistance of the structure forming the " earth " tested with a megger. Also all electric leads, terminal blocks and junction boxes should have been fitted. The electric installation requires testing for continuity and " shorts " with a 2-volt lamp, and in case of an extensive electrical system, the system should be tested for " earths " by means of a bridge megger.

29. All internal control cables should be again tried to ensure that they are working correctly and freely, and that they have not been painted up or otherwise obstructed. They should be protected against corrosion.

30. If not already carried out, a test for interchangeability and alignment of control surface hinges and fittings should be made at this stage; although, normally, this would be carried out much earlier, and would only be made at this stage when there was reason to believe that the component had warped, or that the interchangeability had been otherwise affected.

31. The whole component should then be examined to see that it has been adequately protected by paint or varnish or by other approved methods, and that the required number of coats of protection have been applied.

32. Parts which come into direct contact with the doped fabric are to be painted with dope resisting paint, and all sharp corners which are liable to cut the fabric or the thread securing the fabric shall be either removed or themselves bound with fabric. Generally speaking, metal components are not bound with fabric, but should have all sharp corners removed beforehand. The objection to binding metal components with fabric is that the fabric itself is usually unprotected and tends to retain moisture.

Covered and Doped Components

33. Examination shall be made to ensure that the correct type of seam is employed, and that all hand sewing is carried out with the correct thread, adequately waxed and properly lock-stitched. The attachment of fabric to ribs must be carefully verified for correctness of braided cord, pitch of stringing and knotting of cord.

34. After the first coat of dope is applied, a hole must be cut in the fabric to expose the assembly inspection stamp. The opening is to be covered with a strip of celluloid secured in position by means of a frame-shaped piece of fabric, doped on the main covering. If this is not done it will be found difficult to locate this stamp after covering.

35. On the completion of all processes covered by the covering and doping process label, the latter should be detached and filed for record purposes.

36. After all processes have been completed and all external fittings duly attached, the component will be checked for interchangeability of all hinges and attachments.

37. A special examination should be made to ensure that warping or distortion of the component has not occurred during covering and doping.

38. Drain holes must be carefully checked for position; such holes must be in positions to prevent lodging of water in the component and must not be blocked in any way. A check must be made that all controls are working freely and that they have not been doped up.

39. Provided that the component is in every way satisfactory and fully completed with all necessary identification marking it may be finally approved.

Re-conditioned Components

1. In general, the inspection of a re-conditioned component should proceed precisely as for a new component.

Attention is drawn, however, to the following points:—

2. If new spars are embodied in a component during re-conditioning, only the specified timber may be accepted, alternative timbers being no longer permitted.

On the other hand, existing spars and/or other members, including rib flanges, in which spruce substitutes, formerly approved, have been used, may be permitted if otherwise satisfactory.

The use of cypress is definitely prohibited.

Re-conditioned Spars

3. The following limits may be permitted on the cross-sectional dimensions of re-conditioned spars:—

Plus or minus .03 in. for sections up to 3 in. width or depth.

Plus .03 in., minus .01 in. per inch of width or depth for sections over 3 in. width or depth.

4. All existing, built-up, laminated or solid spars, spindled or otherwise, are acceptable if already embodied in components undergoing re-conditioning, subject to the following conditions:—

(*a*) *Solid Spars.*—Shaky and warped spars may not be accepted.

(*b*) *Laminated Spars.*—Shaky and warped spars are forbidden. All joints should be carefully examined and any spar found with defective joints must be rejected.

(*c*) *Spliced, Solid and Laminated Spars.*—All splices should be examined by removing the fabric binding, and any spar found to have open joints must be rejected.

All splices must be carefully examined for soundness. The only approved types of splice are the plain scarf and the R.A.E. type, the latter taking the form of a dovetail splice with a central square wedge.

Positions of splices must be carefully checked to ensure their being in accordance with the approved drawings. The correct angle of the standard scarfed splice is not less than 1 in 9, and the splice should be suitably pegged with ash pegs.

(*d*) *Horizontal Laminations in Spars.*—Spars composed of horizontal laminations, in which the top and/or bottom laminations contain butt joints, may not be accepted. The binding should be removed if necessary to ascertain if such is the case.

Spars with horizontal laminations in which the intermediate laminations have butt joints are acceptable, provided the two outer laminations are continuous and provided such spars are satisfactory in all other respects.

(*e*) *Box Spars.*—Box spars with continuous or jointed flanges and sides may be accepted. These spars, in general, are covered entirely with glued-on fabric which renders inspection difficult. The fabric or taping should be examined for discoloration which reveals the presence of moisture. If such discoloration be present the entire spar should be unwrapped, as in all probability failure of the glued joints may have occurred. If, on the other hand, no defects are visible, stripping of the fabric need not be made, but a careful examination of the fabric wrapping must be made for evidence of shakes or of broken joints.

All box spars should normally be provided with inspection holes or other approved means of ascertaining the presence and correct location of the internal packing blocks.

Re-conditioned Struts

5. The following dimensional limits may be worked to in the inspection of re-conditioned struts:—

Plus or minus .03 in. for sections up to 3 in., major or minor axis.

Plus .03 in., minus .01 in. per inch of width or thickness on all sections over 3 in., major or minor axis.

These are general limits applicable in all cases, but in the case of an interplane strut in which the main portion of the strut is well up to size and true to nominal shape, the minus limit may be increased to a total of 0.1 in. provided the deficiency only arises because a portion of the rear fairing of the strut is absent.

Built-up and Composite Members other than Spars and Struts

6. All built-up members shall be inspected similarly to spars and struts of identical type.

Particular attention must be given to all such built-up members during reconditioning, especially in cases in which oil and water soaking has occurred during service.

7. Wherever water stain occurs on a part, it must be carefully examined for evidence of incipient decay, failure of glued joints and/or fungoid growth (including dote).

8. Streamline wires and tierods must bear evidence of their previous inspectional history, otherwise they must be rejected.

Bowing of Components

9. It may occasionally happen that a spar or strut has developed a slight bow either during storage or during the concluding stages of manufacture; as such a defect cannot readily be rectified at this stage the following limits are laid down for guidance in exceptional cases:—

10. *Limits of Bow permissible in Struts.*—The maximum bow permissible upon a strut, provided that such bow is smooth and regular throughout the length of the strut, is as follows:—

For Metal Struts—1/600th of the length of the strut.

For Timber Struts—.03in. for struts up to 3ft. long, .01in. per foot run for struts over 3ft. long.

11. *Limits of Bow permissible in Main-Plain Spars.*—Horizontal Bow—A main plane which has developed a slight regular bow in the direction of its width, *i.e.*, in the plane of the component, need not involve the rejection of a component otherwise satisfactory provided there is definite evidence that the timber in the spar is satisfactory and that the spar imposes no unreasonable stress anywhere, either on the ribs or internal bracing wires; also, provided that it does not interfere with the ready assembly of the component to another nor affect interchangeability in any way. If, however, such spars are found to be of hard-grained timber, the component may not be accepted.

12. *Vertical Bow.*—A main plane spar which has developed a smooth, regular bow throughout its length, *i.e.*, at right angles to the plane of the component, may be accepted, provided:—

(*a*) That the total bow does not exceed $\frac{3}{8}$in.

(*b*) That when the component is laid along a flat table only very slight hand pressure is required to straighten the spar.

(*c*) That the character of the bow is such that it will rig out during the erection of the component on the aircraft, without any undue stress or effort being required in the external bracing to maintain the straightness of the spar.

13. All spars must be entirely free from hard-grained timber or other defects and any bow must consist of one regular curve only.

14. Spars with local bows, two or more bows in one direction or bowed in both directions, are not permissible.

15. In the case of an erected component, in which vertical bow of a spar still persists after rigging, such bow must not exceed 1/6ooth of the length between points of support, *e.g.*, strut positions.

Petrol, Oil and Water Tanks

General

1. This paper excludes reference to special types of tanks such as those of aluminium or stainless steel and self-sealing types, and deals only with tanks of standard construction in tinned steel, brass and copper; although the same principles of inspection and the same tests apply.

2. The soundness of construction of a tank, its ability to satisfy all test requirements and the absolute cleanliness of its interior are prime essentials to which particular attention must be given. All inlet and outlet pipes must be carefully examined to ensure their absolute freedom from obstruction of any kind, and an equally close inspection must be made of all vent holes and/or other venting arrangements.

Interchangeability

3. All tanks must be checked for interchangeability of fixing brackets or other attachments.

4. Interchangeability of all screwed connections must have been proved by the use of approved gauges.

Materials

5. The Inspector is responsible for ensuring that all materials, fittings and parts used in the manufacture of a tank are fully in accordance with drawings and appropriate specifications.

Manufacture

6. All soldered details shall be carefully washed with running hot water as soon after soldering as possible until all excess of flux has been removed and directly thereafter the parts are to be thoroughly dried. In the case of soldering pastes usually consisting of zinc chloride in a mineral jelly base, hot water alone may not possibly remove them. Scrubbing with petrol will, however, remove the mineral jelly, but owing to these difficulties such pastes are not recommended for general tank work.

7. All the splashes, blobs and feathers of solder must be removed before the above washing is carried out.

8. Grade " B " solder is to be used and fluxes must be of an approved type.

(N.B.—For composition of Grade " B " solder see " Radiators " par. 3.)

9. If a solder bath is employed for fittings, it must be maintained at a uniform temperature and be controlled pyrometrically.

10. All bent and welded steel fittings must be given their appropriate heat-treatment before assembly.

11. In the absence of the necessary particulars on the drawings, all tank joints and seams must be of the standard double lap, grooved or knocked up type.

12. Rivets should be well tinned before insertion.

13. Care must be taken to avoid scriber and/or centre punch marks on all plates owing to their liability to open during working or bending of the plates, and to rusting of the exposed metal.

14. Any exposed edges of the metal must be cleanly finished off to prevent the development of incipient cracks and all such edges must be thoroughly tinned to prevent rusting.

Process Inspection

15. During construction and immediately before closing up the tank by securing the end plate, a careful inspection must be made to insure that all internal surfaces have been thoroughly cleansed and that all splashes, feathers and blobs of solder have been removed as these are extremely liable to become detached at a later date.

Testing

16. All tanks after completion must be subjected to the following tests:—

I. *Weight.*—When completed and without loose fittings, the tank must not exceed the specified limits of weight, if any.

II. *Capacity.*—The first tank off any batch shall be tested for capacity by filling with paraffin. The quantity used shall be measured by draining off into a calibrated vessel.

On tanks of greater than 10 gallons capacity, the capacity of each tank must not vary by more than plus or minus 2 per cent. from that specified, notwithstanding that dimensionally the tank must be within the limits shown on the drawings.

Similarly on small tanks of less than 10 gallons the capacity shall not be less than minus 2 per cent. from that specified.

NOTE.—In the subsequent marking of oil tanks for capacity, only the net volume remaining after allowing for the air space should be stated. This is essential if over filling of oil tanks in service, with consequent restriction of air space, is to be avoided.

III. *Pressure Test.*—Each tank is to be whitened around the seams and fittings and at least 10 per cent. of its specified capacity of paraffin or other approved liquid poured in. The tank is then to be subjected to an air pressure as stated below (unless otherwise stated on the drawings) and turned about in all directions to ensure the paraffin reaching all portions of the interior. The pressure must be held without loss. The duration of the test must not be less than 20 minutes. The pressure shall be recorded by means of a gauge having a range not exceeding 0-10 lbs., calibrated into readings of $\frac{1}{4}$ lb. per square inch, or by other approved method:—

(*a*) *Tanks for Experimental Aircraft and of New Design.*—A pressure of "x" times the static head where "x" is the load factor on the front spar of the aircraft or of $1\frac{1}{2}$ lbs. per square inch, whichever is the greater, shall be imposed. For the purpose of this test the static head will be assumed to be the depth of petrol in the tank when full with the aircraft in the normal flying position, and any support normally given to the tank may be reproduced in this test and, furthermore, the top may be given additional support to prevent serious distortion under test, except in the case of pressure tanks or where the tank in use is subjected to a superimposed head.

During this test there should be no failure of seams or joints and no leakage.

(*b*) *Production and Subsequent Tanks.*—Where the tank is identical in design with a "type" tank which has satisfactorily passed test (*a*) above, a routine test of $1\frac{1}{2}$ lbs. per square inch for a period of 20 minutes shall be imposed upon the unsupported tank as a check upon workmanship.

17. In carrying out the above tests on petrol, oil or water tanks, a head of 3 feet of petrol, 2.5 feet of oil or 2.3 feet of water has to be reckoned as equivalent to a pressure of 1 lb. per square inch in fixing the necessary air pressure.

Cleanliness and Sealing of Outlets

18. The completed tank must be systematically inspected to insure that the inside is absolutely clean and free from foreign matter, loose pieces of solder, etc.

19. Cleanliness of, and removal of chlorides from, the completed tank must be ensured by washing out thoroughly with hot water followed by careful drying. Such drying may readily be effected by means of hot air blown through the tank or by heating the tank in a suitable oven or its equivalent, provided the temperature does not exceed 250° F. In using an oven, exit for any steam generated must be provided.

20. The interiors of all tanks are to be visually examined by means of an electric inspection lamp which will enter and reach all portions of the tank, or by means of a mirror and an electric bulb attached to a rod, in the form of a periscope, the mirror being arranged so that it can be set at any desired angle.

21. During storage or transport all outlet and inlet openings must be carefully sealed in an approved manner by covers, so as to prevent foreign matter entering the tanks. Filler caps should be secured by means of a wire passed round the filler pipe and looped over the cap to prevent the latter being fully unscrewed. The wire loop should be sealed.

RADIATORS

General

1. The inspection of radiators is of prime importance as upon it depends the safety and functioning of the cooling system of an aircraft. Apart from soundness of construction of the tankage and the tube-block and the ability of the entire radiator to satisfy the required tests, absolute cleanliness and freedom from loose material of the interior is essential. Particular attention must also be given to all inlet and outlet pipes to ensure their absolute freedom from obstruction of any kind, and an equally close inspection must be made of all venting arrangements.

Material

2. The Inspector must ensure that all materials, fittings tubes and other parts used in the manufacture of radiators are fully in accordance with drawings and appropriate specifications.

3. All soft solder used in the construction of radiators shall be in accordance with the specification for "Grade B" solder (Tin 49-52 per cent., Antimony not more than 3 per cent., Lead remainder). Since the dipping-bath solder is liable to lose some of its tin content, periodical checks of the solder must be made from time to time by analyses of samples taken from the bath. In no circumstances may the tin content of the bath be allowed to fall below 45 per cent.

4. No fluxes employed in soft soldering may contain any free minerai acid. The use of ordinary "killed spirits" is forbidden.

Manufacture

5. All soldered surfaces should be carefully washed with hot water to remove all traces of chlorides arising from the soldering fluxes. All tube-blocks must be carefully washed in hot water as soon after dipping as possible, and before assembly to the casing.

6. The solder-dipping bath for the tube-block must be controlled by means of a pyrometer so as to ensure a safe dipping temperature. This must be determined by experience in each particular case. In addition, the pyrometer may also be employed to indicate when the dipping bath becomes deficient in tin content, this being indicated by a high rise from the normal working temperature required to give the necessary fluidity of the solder.

7. All copper piping and bent and welded steel fittings must be given the appropriate heat-treatment before assembly.

8. In the absence of the necessary particulars on the drawing, lap joints forming the corners of tankages must be of double L form, both plates being sweated on two sides of the angle forming the corner.

Process Inspection

9. The Inspector must ensure that the constructor has carried out all necessary washing of casing and tube block at the time of manufacture.

10. In checking for dimensions, particular care must be exercised that the tubes have been correctly assembled in the block, that there are the correct number of rows of tubes, and that in no case is the water-way between adjacent tubes less than the minimum specified. This can readily be determined so far as the marginal tubes are concerned by direct measurement; in the main body of the tube-block, however, this can only be done by noting the number of tubes in a length of, say 12 inches, in all directions, and calculating the average width of water-way between them.

11. The depth of the solder-dipping must be checked to ensure that it is not less than 3mm. but does not exceed 4mm. Records should be made of the weight of the solder picked up during the process of dipping of the tube-blocks, so as to ensure that no loose solder is present in any one of a batch of similar tube-blocks.

12. Care must be taken also to ensure that the tube-block and casing accurately fit one another.

13. The operation of loading the tube-block to the casing must be specially watched to ensure that the marginal soldering is satisfactorily carried out. This is particularly important as no check upon the marginal soldering can be made upon a completed radiator.

Testing

14. After completion, the radiator must be subjected to the following tests:—

I. *Dry Weight.*—The weight of the completed radiator must be within the limits of weight specified.

II. *Capacity.*—The first radiator off any batch shall be checked for capacity.

III. *Hot Water Pressure Test.*—The radiator will be completely filled with hot water at a temperature of not less than 180°F., and must withstand a pressure of 6 pounds per sq. inch for at least 10 minutes without leaking.

IV. *Cold Water Pressure Test.*—The radiator, after having been emptied of the hot water used in III. above, must be *immediately* filled with cold water and subjected to a pressure of 6 pounds per square inch for a period of not less than 30 minutes, during which there must be no leakage at any point.

V. *Flow Test.*—Each radiator, under a head of 7 feet above the radiator inlet, must pass the specified quantity of water per minute under the following conditions:—

(*a*) The total head of water, measured from the surface of the water in the supply tank to the level of the inlet of the radiator under test, must not at any time exceed 7 feet.

(*b*) Any outlet pipe or branch, attached to the radiator during the test so as to give a clear discharge into the measuring vessel, must have its outlet not more than one foot below the radiator outlet.

(*c*) During test the radiator must be supported in a position corresponding to its normal position upon the aircraft, *e.g.*, a radiator which is supported vertically in an aeroplane must be flow tested in a vertical position; it may not be flow tested horizontally, neither may it be turned upside down, nor have the inlet and outlet openings transposed. During test it is essential that the radiator runs full and that no air is trapped anywhere in the system.

(*d*) The duration of test may not be less than 20 seconds, the time being recorded by means of a stop-watch after steady conditions of flow from the radiator have been attained.

(*e*) The quantity of water issuing from the radiator outlet during the timed period must be measured directly by means of a calibrated measuring vessel or by weighing.

In order to obtain the best conditions the horizontal cross-section of the supply tank should be kept as large as possible and, in general, to avoid obstruction, the delivery pipe from the tank to the radiator under test should be 3 in. diameter. The size of the pipe should be capable of dealing with rates of flow up to 100 gallons per minute.

Cleanliness and Sealing of Outlets

15. The completed radiator must be systematically inspected to ensure that the inside is clean and absolutely free from foreign matter, loose pieces of solder, etc. All pipes, inlet, outlet and steam venting must be checked for freedom from obstruction.

16. During storage or transport, all inlet and outlet openings must be sealed in an approved manner by covers so as to prevent foreign matter entering the radiators. Filler caps should be secured by means of a wire passed round the filter neck and looped over the caps to prevent their being unscrewed. The wire loops should be sealed. No solder may be permitted on or near screw threads.

17. Interchangeability of all screwed connections must be checked by means of approved gauges. All pipes which will be required to enter rubber tubing must have their ends carefully tinned and well rounded to prevent cutting of the rubber.

Approval of Completed Radiator

18. Approval of the completed radiator signifies that there is definite evidence that

(*a*) All parts and processes have been previously approved by an authorised inspector;
(*b*) All material and workmanship are of the necessary standards;
(*c*) All tests have been satisfactorily carried out;
(*d*) Assembly is complete to schedule and contains all necessary identification marking;
(*e*) All painting, or other protection specified, has been satisfactorily carried out.

Repaired Radiators

1. *Radiators requiring complete new Tube Blocks.*—After removal of the old tube block from the casing, the latter must be carefully examined for mechanical or corrosive damage.

2. All traces of corrosion and/or foreign matter must be removed and the casing rectified to the condition demanded for new radiators, so far as general soundness is concerned.

3. Thereafter, the inspection will proceed precisely as for new radiators, particular care being given to the requisite widths of waterways. The usual hot and cold water pressure tests and flow tests will be imposed upon completion.

4. *Radiators which are to have old Tube Blocks Repaired.*—No repair or plugging of tubes is permitted and any tubes which leak at points other than soldered joints must be replaced, particular care being exercised in avoiding the ingress of solder into the interiors of the radiators. See paragraph 8 of B.E.S.A. Specifications T.47 and T.48.

5. Inspection will proceed as above so far as the necessary tests are concerned.

Note on Soldering Fluxes

1. Before any flux for soft soldering or sweating operations is used for any purpose of aircraft construction, it must be tested to ensure that it is free from mineral acid to minimise the possibility of subsequent corrosion of the material at or near to the soldered joint.

2. Every consignment of a proprietary brand of flux is to be tested prior to use and, in addition, periodic check tests of the fluxes as used in the workshop should be carried out.

3. The flux should be issued to the workshops daily from approved stock, preferably in earthenware or glass jars.

4. The test on liquid flux is effected by dipping methyl orange paper into the flux after it has been diluted with an equal volume of water. If the paper turns pink, mineral acid is indicated and the flux is accordingly unserviceable.

5. Fluxes purchased in solid form should be prepared in accordance with the manufacturers' directions and the test carried out as above after dilution with an equal volume of water.

6. Fluxes derived from a jelly base can properly be tested only at an approved laboratory.

7. After soldering, the joint must always be thoroughly wiped clean and washed in hot water. Joints soldered with the aid of paste fluxes must be cleaned with petrol prior to washing.

Petrol Oil and Water System Accessories

General

1. The correct functioning of the fuel, lubrication and cooling systems of an aircraft being entirely dependent on the satisfactory functioning of *all* of their individual component units, it is essential that all cocks, valves, pumps, filters and other accessories must be separately inspected prior to their installation.

Materials and Details

2. The inspector must ensure that all materials and fittings used in the construction of each accessory are fully in accordance with drawings and appropriate specifications. All separate details must bear the required part numbers and evidence of a prior authorised inspection.

Testing

3. In addition to any tests called for on its detail parts, the completed accessory must be subjected to the pressure flow and/or delivery tests called for on the drawing or specification.

4. A careful examination must also be made to ensure the entire absence of solder, grit, or any foreign matter liable to cause leakage, obstruction of the flow, or faulty working of the accessory.

5. In the absence of specified tests, the undermentioned tests will be applied.

Petrol Cocks and Valves

(I.) *Pressure Test.*—Petrol cocks and valves must withstand an internal pressure of 15 lbs. per square inch without leakages. This test may be carried out, using paraffin internally, the casing being whitened externally; or by means of internal air pressure, with the cock or valve wholly immersed in petrol or paraffin.

Special tests may be laid down in the case of particular cocks which are either of proprietary manufacture or are subject in service to considerable heads of petrol, as in the case of airships.

(II.) *Flow Test.*—Under a standard head of one foot, each cock or valve, when open, must pass petrol at not less than the minimum rate in gallons per hour called for on the drawings or specification. (It should be noted that any liquid other than petrol will give an erroneous idea of the rate of flow obtainable.)

The above tests must be carried out to ensure that the cock or valve functions correctly in all positions open or closed.

Drain Cocks

Each drain cock, with a film of oil between the plug and the body, must withstand a test pressure of 15 lbs. per square inch without leakage.

Pumps

Each petrol pump must be pressure-tested to ensure the soundness of its body to 15 lbs. per square inch and, in all cases, a capacity delivery test must be carried out under prearranged conditions of speed and suction and delivery heads.

Rotherham Type Air Pump

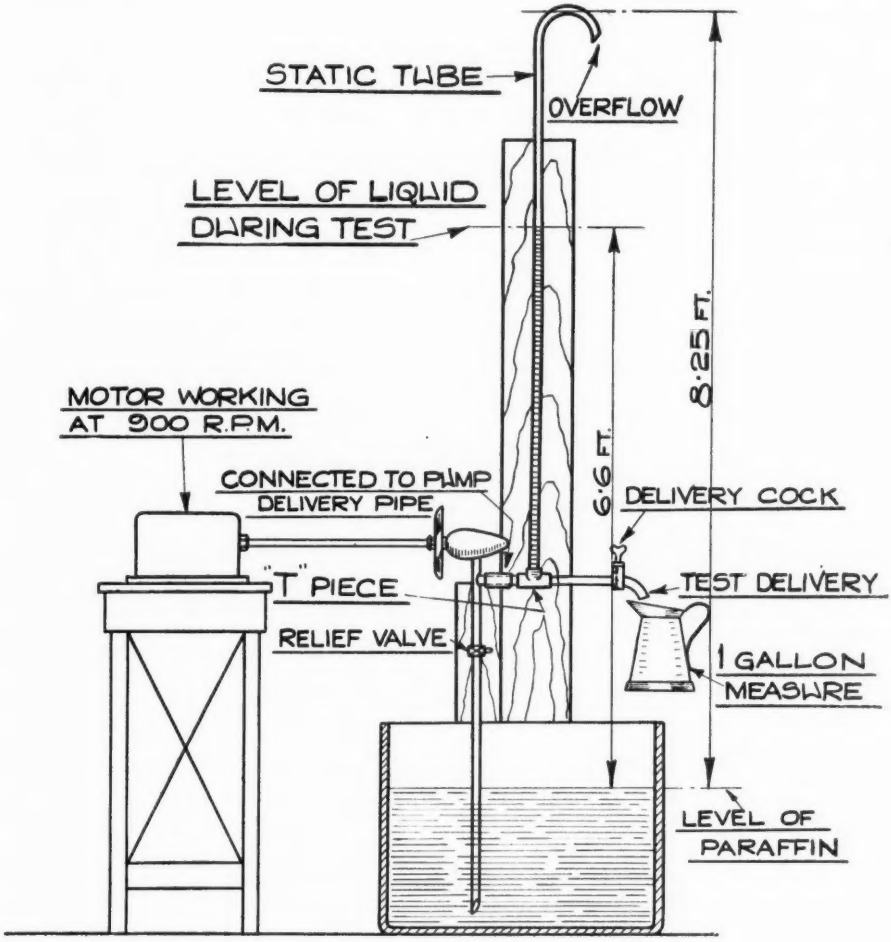
Each pump must have its delivery connected to a closed container of 5 galls. capacity. A standard 5-gallon drum will be found most useful for the purpose. When run at a propeller shaft speed of 1,450 revolutions per minute, it must raise the pressure in the container from 0 to 6 pounds per square inch during an interval of time not exceeding 80 seconds, with the relief valve fully closed. Thereafter, to check the setting of the relief valve, when run at the same speed, the pump must raise the pressure of the container from zero to 6 lbs. per square inch during a period not exceeding five minutes.

Vickers Hand Petrol Pump, Mark III.

This pump must be tested with petrol, using hand operation, and must give a rate of delivery of not less than 140 gallons per hour under a suction lift of 3 feet and a delivery head of 3 feet at approximately 100 strokes per minute (maximum).

Vickers Centrifugal Petrol Pumps

Each completed pump must undergo a running-in test on the bench against a pre-arranged head, followed by a delivery test under the conditions of suction and lift shown below. After the tests, the soundness of the glands and joints must be tested by means of a further pressure test, and in addition care must be exercised to ensure that the pump has been finally adjusted to allow for the thrust imposed by the windmill in flight, so that no binding of the impeller on the casing can take place. The moment required to turn the spindle, after the tests, must also be measured.



DIAGRAMMATIC VIEW OF TESTING ARRANGEMENTS FOR DE H 9A, MARK IV, PETROL PUMP

FIG. 7.

The following table gives details of the tests required on Vickers Centrifugal Petrol Pumps:—

Type of Pump.	Internal Pressure Test for Porosity.	Running-in Test.	Delivery.	Test on Glands and Joints.	Spindle Test.	Setting of Impeller.
3in. Mark II.	15 lbs. per sq. in. internal air pressure.	Run at 4,000 r.p.m. for 15-20 mins. at 5 lbs. per sq. in. delivery.	Not less than 120 galls. per hour to be delivered at 4,000 r.p.m. with 3 lbs. per sq. in. suction and 7 lbs. per sq. in. delivery.	10 lbs. per sq. in. internal air pressure.	Impeller must turn with a turning moment not exceeding 24 inch-ounces.	Set with .01in. clearance between vanes and volute.
2in. Mark VI.	15 lbs. per sq. in. internal air pressure.	Run at 4,000 r.p.m. for 15-20 mins. at 3 lbs. per sq. in. delivery.	Not less than 60 galls. per hour to be delivered at 4,000 r.p.m. with open suction and 3½ lbs. per sq. in. delivery.	10 lbs. per sq. in. internal air pressure.	Impeller must turn with a turning moment not exceeding 24 inch-ounces.	Set with .01in. clearance between vanes and volute.

De Havilland Petrol Pump (Mark III. and Mark IV.)—Fig. 7

In testing the above pump the delivery pipe must be fitted with a tee-piece, one side of which connects with an open-ended tube, the other with a delivery cock. With the cock closed and when the pump is run at 900 revolutions per minute, propeller speed, the relief valve must be set so that it by-passes all the liquid pumped when the level of the liquid in the open-ended tube is 8.25 feet above the level of the liquid in the supply tank. With this setting of the relief valve and at the same pump speed, the delivery cock is then to be opened until the level of liquid in the static tube falls to 6.6 feet above the level of liquid in the supply tank. Under these conditions the pump must deliver not less than 130 pints of petrol per hour.

After the above test, the pump must be capable of being revolved with a turning movement of 3.5 inch ounces, applied at the propeller spindle.

Filters

In general, each filter must be tested with an internal air pressure of 15 lbs. per square inch, and must show no signs of leakage when the filter is completely immersed in petrol.